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INTERTIDAL AND ADJACENT UPLAND HABITAT IN ESTUARIES LOCATED ON THE EAST COAST OF VANCOUVER ISLAND – A PILOT ASSESSMENT OF THEIR HISTORICAL CHANGES

Alison Campbell Prentice
W. Sean Boyd

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ABSTRACT

This pilot study investigated historical change to estuaries on the east coast of Vancouver Island. Within the estuary intertidal boundary, the most serious habitat loss was a 32% decrease in marsh habitat which occurred at the turn of the 20th century when early settlers dyked upper marshes for agricultural purposes. During the last 40 to 50 years, loss of marsh habitat has slowed and has been offset by dyke breaching and vegetation transplanting. Intertidal substrate and subtidal water habitats have experienced relatively high losses in recent years, however those losses represent only 2% of their original areas. The major threats to estuarine intertidal habitats were log handling, log storage, pulpmill construction, and marina expansion. In upland areas adjacent to estuaries, forest, meadow, and agricultural land have been increasingly replaced by log handling industries, logged areas, and residential development. Aerial photographs were useful in determining habitat change even though some problems with time period coverage and scale were experienced.

RÉSUMÉ

Cette étude pilote avait pour but d'examiner l'évolution des estuaires sur la cote est de l'île Vancouver. Dans la zone intertidale des estuaires, la perte d'habitat la plus importante a été une diminution de 32% de marais survenue au début du 20^{e} siècle, lorsque les premiers colons ont endigué les marais supérieurs pour l'agriculture. Au cours des 40 à 50 dernières années, cette perte d'habitat dans les marais a ralenti; elle a été compensée par les brèches faites dans les digues et par la transplantation de végétaux. Le fond intertidal et les habitats aquatiques infralittoraux ont subi des pertes relativement élevées ces dernières années, mais ces pertes ne représentent que 2% de leur étendue originelle. Les menaces les plus sérieuses pour les habitats intertidaux des estuaires ont été les exploitations forestières, l'entreposage du bois, la construction de fabriques de pâte à papier et l'agrandissement des marinas. Dans les hautes-terres adjacentes aux estuaires, la forêt, la prairie et les terres agricoles ont progressivement été remplacees par des industries forestières, des zones bûchées et des lotissements résidentiels. Malgré les problèmes de couverture des périodes de temps et des problèmes d'échelle, les photographies aériennes ont aidé à déterminer les changements dans l'habitat.

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1. INTRODUCTION

Estuaries are currently the focus of considerable attention for protection in British Columbia. There are three prime reasons for that attention. First, estuaries provide critical habitat for migrating and wintering birds and anadramous salmonids. About 50% of the 10.8 million waterfowl in the Pacific flyway use coastal migratory routes and an estimated 1 million ducks and geese winter along the British Columbia coast (Hunter and Jones 1982); estuaries provide essential food and cover for many of those birds. All 5 species of Pacific salmon (but in particular chinook, chum, and coho salmon) use estuaries for foraging, as refuges from predators, and as physiological transition zones from fresh to salt water (Healey 1982; Simenstad et al. 1982). Second, estuaries are few in number and sparse in distribution. They constitute only 2.3% of British Columbia's 27,000 km coastline (Hunter and Jones 1982) and only 0.02% of British Columbia's areal extent (Boyd 1983). Third, estuaries have been under considerable threat, particularly from early farming interests that turned upper marsh into arable land. Of the documented loss to estuarine area in Washington, Oregon, and northern California, 90% was due to dyking for agriculture prior to the 1930's (Boule and Bierly 1987). The Fraser River estuary experienced a 70% loss of intertidal salt marsh for similar reasons (Romaine et al. 1976). More recently, development activities associated with the forestry industry and urbanization have been concentrating adjacent to estuaries.

While the importance of estuaries to fish and wildlife and their sparse distributions have been well documented, little detailed information exists with which to assess the amount, rates, and types of estuarine habitat alienated in recent years and the reasons for those alienations. This pilot study attempted to fill those information gaps for one of the most developed portions of British Columbia: the east coast of Vancouver Island. This study supplements two previous studies on wetland alienation in the interior of British Columbia (Cariboo-Chilcotin area and South Thompson-Okanagan and Peace River-Fort St. John areas of British Columbia) undertaken by the Canadian Wildlife Service (McKenzie 1983, 1985).

The objectives of this study were to:

1. determine the areal extent of the different habitat types and land uses in each estuary over time, beginning with the earliest available air photos,

2. calculate the losses and gains of the different habitat types and land uses over time and determine their rates of change,

3. attempt an estimate of the amount of marsh habitat lost to dyking around the turn of the century,

4. determine the habitat types most affected by log storage over time,

5. assess the usefulness of air photographs in determining historical habitat change, and

6. make recommendations regarding a full scale study.

2. METHODS

The study estuaries were located between Duncan and Campbell River on the east coast of Vancouver Island. They were selected on the basis of their high value ratings by the B.C. Ministry of Environment and Parks (Hunter et al. 1985; Appendix 1). The estuaries investigated were those located at the Cowichan River, Chemainus River, Ladysmith Harbour, Nanaimo River, Nanoose/ Bonell Creeks, Northwest Bay, Englishman River, French Creek, Little Qualicum River, Big Qualicum River, Baynes Sound, Courtenay-Comox area, Oyster River/ Black Creek, and Campbell River (Figure 1).

Habitat types and land uses were taken from the B.C. Ministry of Environment and Parks estuarine classification system (Hunter et al. 1983). They were: intertidal substrate (mudflats, sandflats and gravel), intertidal marsh, river channel, tide channel, subtidal water, backshore meadow (natural and manmade upland vegetation dominated by grasses and forbes), shrub, and forest. Land uses were divided into agriculture (grazing and cultivation), log handling (log sorting areas, log or lumber storage on land, sawmills and log dumps), pulp mills, logged areas, marinas (water and parking), residential areas, industrial areas, general parking, and other uses. Intertidal log storage was treated separately from the above land uses since the habitat affected was not permanently lost.

Each estuary was divided into an intertidal zone and an adjacent upland zone, with the interface being mean higher high water on large (spring) tides. The lower boundary of the intertidal zone was set at the lower extreme of intertidal substrate at the seaward edge (approximately chart datum on 1:15840 planimetric base maps). The upper boundary of the upland zone was set at some arbitrary anthropogenic landmark(s) (e.g. roads and railways). The intertidal and upland boundaries met where chart datum coincided with the shoreline, generally at the outer edges of bays containing the estuaries. Where an adjacent, prominent spit of land was present (e.g. Nanaimo, Little Qualicum river estuaries), habitat and land uses on that spit, as well as intertidal land on its far side, were included in this assessment.

Air photos were selected and analyzed at the MAPS B.C. office (Ministry of Environment and Parks) in Victoria and at the air photo library in the Geography Department at the University of British Columbia, Vancouver. Photo coverage was inconsistent with respect to time period; photos for some areas were available from 1932 to 1986 whereas for other areas photos were available from only 1951 to 1984 (Appendix 2). The scale of photography varied from 1:5000 to 1:31680. The dates of air photos investigated were: (1) "prior to 1951", (2) 1957 or 1958, (3) 1962, 1964 or 1965, (4) 1975, and (5) 1984 or 1986. Some dates varied by a few years due to incomplete photo coverage.

Standard air photo interpretation was used to determine land uses and habitat types. They were traced from the air photos onto vellum and then transferred to planimetric base maps at a scale of 1:15840 using an epidiascope[1] (Appendix 3). In addition to air photo analysis, existing reports and maps were used to determine the location of marshes and the identity of industrial buildings (Appendix 3). Ground truthing was undertaken for the estuaries between Duncan and Big Qualicum River.

[1]Those final maps are located at the Canadian Wildlife Service office, Delta, B.C.

The areal extent of the different land uses and habitat types in each estuary for each time period were determined using a graphics tablet and Apple II+ computer. Each area was digitized 3 times and an average calculated. Total losses and gains and rates of change for each time period were calculated using the above data for each habitat type and land use in each estuary. The data were also summarized for the entire study period and for all estuaries as a group.

An estimate of the amount of marsh habitat lost to dyking prior to the first air photos was made by analysing the most recent air photos. The amount of agricultural land between dykes and, what appeared to be, a pre-dyking, upland boundary near existing marsh was calculated.

3. RESULTS

3.1 Land uses in the study estuaries - an historical perspective

Cowichan River estuary (Table 1 and Figures 2 and 3)

Settlement of the Cowichan River estuary began in 1862 with the arrival of settlers intent on farming (Cowichan Estuary Task Force 1980). A large portion of the estuary was dyked for agriculture at that time and marsh and meadow habitat were lost. An extension of the Canadian National Railway was built to the estuary in 1925 to connect inland logging operations with direct coastal access. That railway was located on a wharf and pile-supported causeway which were completed in 1933 and later reconstructed on filled estuarine land (Cowichan Estuary Task Force 1980). The causeway resulted in the loss of marsh, meadow, intertidal substrate, and subtidal water habitat. By 1957, two small areas on the south side of the estuary had been filled for log dumps. Log handling activity increased in 1965 when the Westcan lumber storage facility was built by filling intertidal substrate and subtidal water habitat. The Doman sawmill and log and lumber storage area were built in the early 1970's by filling agricultural land; an area was also dredged for log storage. Between 1962 and 1975, a dyke was built south of the railroad causeway to create agricultural land from marsh habitat (Dawe and Jones 1986). That trend is now being reversed. By 1984, a dyke had been built north of the Doman sawmill inside an existing dyke. That left some agricultural land outside the new dyke which was subsequently returned to marsh habitat. In 1987, a dyke was naturally breached at the Koksilah marsh south of the railroad causeway. That also returned agricultural land to marsh habitat. The main land uses today are agricultural and log handling. The subtidal water habitat is heavily used for log storage.

Chemainus River estuary (Table 2 and Figures 4 and 5)

The Chemainus River estuary was settled by 1870 and marsh and meadow habitat were subsequently dyked for agriculture. In 1912, the Canadian National Railway line was completed to Crofton (Bell and Kallman 1976a) and by 1933, docking facilities had been constructed for deep sea vessels. A railway log dump had been completed by 1950 but was removed by 1957. The docking facilities were expanded between 1950 and 1957 through the filling of subtidal

water habitat. The Crofton pulp mill started production in 1958 (Lyons 1958). By 1984, a lumber storage area had been created from intertidal substrate and subtidal water habitats. Today, the main land uses are agricultural and the Crofton pulp and paper mill. Log storage is common on intertidal substrate and subtidal water habitat.

Ladysmith Harbour (Table 3 and Figures 6 and 7)

At Ladysmith Harbour, meadow habitat was lost to agriculture through dyking when the first settlers arrived around 1862. Log handling activities were present by 1950 when an area was dredged for a log dump. Residential land use appeared between 1950 and 1957. By 1962, another area of the harbour had been dredged for a log dump and a sawmill was in operation nearby. That sawmill was removed by 1984 but by 1975 the Schoen Timber Ltd. sawmill and log and lumber storage area was in operation. That operation caused loss of agriculture and meadow habitats; intertidal substrate was also filled. Ivy Green Provincial Park, located on the south side of the harbour, became Stzuminus tribe park and campground by 1986. The main land uses today are agricultural, residential, and log handling.

Nanaimo River estuary (Table 4 and Figure 8 and 9)

At the Nanaimo River estuary, agricultural land behind dykes was present by 1932. Marsh and meadow habitats were probably lost through dyking when the first settlers arrived in the 1860's. An assembly wharf was built on the west side of the estuary between 1935 and 1938. Log storage on intertidal substrate and subtidal water began in 1948 and destruction of eelgrass was noted (Bell and Kallman 1976b). The Harmac pulp mill was completed in 1950 resulting in the filling of intertidal substrate and subtidal water habitat on the far side of the spit (not in the bay itself). The C.I.P.A. Lumber Co. sawmill was completed just north of the assembly wharf in 1960. The Mayo Lumber Co. sawmill was established between 1957 and 1962 and a wharf was built by filling intertidal substrate. The Harmac pulp mill and assembly wharf were both expanded by 1962 and 1975. By 1986, a new pulp mill and assembly wharf had been built on Duke Point. Today, the main land uses at the Nanaimo River estuary are residential, agricultural, log handling, and the pulp mills. Log storage continues to occur on intertidal substrate and subtidal water habitat.

Estuary of Nanoose/Bonell Creeks (Table 5 and Figures 10 and 11)

Agricultural land was present by 1949, probably located on meadow and marsh habitats at the time of the first settlers. The Nanoose church camp was present by 1962 on meadow and forest habitat. Most of the estuary is now part of the Qualicum National Wildlife Area, managed by the Canadian Wildlife Service. The main land use today, therefore, involves wildlife habitat management. Residential areas and a church camp constitute the remaining land uses.

Northwest Bay (Table 6 and Figures 12 and 13)

The intertidal substrate and subtidal water habitats of Northwest Bay have been used for log storage since 1949. The Macmillan-Bloedel log handling area was built in 1975 and an area of intertidal substrate was filled to create a log dump. Otherwise, the estuary was relatively pristine until 1975 at which time residential land use and log handling activities became evident.

Englishman River estuary (Table 7 and Figures 14 and 15)

By 1949, the main land use on the Englishman River estuary was log storage in the tide channels, which continued until between 1962 and 1975. Residential land use began by 1957 as did industrial use (a community centre). A water canal was built by 1957 by a previous land owner who wanted to create a home resembling Venice, Italy (Surfside Trailer Park manager, pers. comm.). A bridge and 2 dykes were built in 1969 isolating some marsh habitat. One of those dykes was breached in 1979, returning some land to marsh habitat (Dawe and McIntosh 1987). A campsite was built in 1980. The main land uses today are residential, industrial, a campsite, and a water canal.

French Creek (Table 8 and Figures 16 and 17)

The main land use is a marina which was built by 1957. That marina was expanded by 1975 and is now the terminal for the ferry to Lasqueti Island.

Little Qualicum River estuary (Table 9 and Figures 18 and 19)

At the Little Qualicum River estuary, a sawmill was located in the estuary from 1947 to 1950 (Dawe and White 1982). Log storage was present in the tide channels and river channel in 1962 but was absent by 1975. By 1962, marsh habitat had been dredged, creating a new river channel. That was done to prevent erosion of private property (N.K. Dawe, pers. comm.). By 1975, residential use had increased and agricultural use had decreased. The estuary is now part of the Qualicum National Wildlife Area, managed by the Canadian Wildlife Service. Habitat management for wildlife, therefore, is the main land use activity today.

Big Qualicum River estuary (Table 10 and Figures 20 and 21)

The main land use is a campsite that was created from meadow habitat by 1975. Logs were stored in the river channel until 1975.

Baynes Sound (Table 11 and Figures 22 and 23)

At Baynes Sound, agriculture began in the 1860's and has increased in intensity while the area occupied by industrial activity has decreased. Union Bay, at the north end of Baynes Sound, was home to a coal shipping terminal in the late 1800's. A railway line was constructed in 1889 to connect coal mines in Cumberland with the dock and coke ovens at Union Bay. Canadian Collieries Ltd. had two coke ovens and a dock with loading chutes for deep sea vessels.

The dock and buildings were demolished in 1966 (Patterson 1983). Marsh area had been dyked by 1951 in Mud Bay and Fanny Bay. Logs have been stored on intertidal substrate and subtidal water since 1951. Log handling was in existence at Mud Bay by 1964 and north of Union Point by 1975. The marina in Mud Bay (built on intertidal substrate) was completed by 1964. The ferry terminal at Buckley Bay (serving Denman and Hornby islands) was completed by 1975 resulting in fill on intertidal substrate habitat. The Canadian Wildlife Service has acquired upland habitat adjacent to the lagoon at Mud Bay. It will form a third unit of the Qualicum National Wildlife Area. The main land uses today are agricultural, residential, industrial, log handling, and a marina.

Courtenay-Comox area (Table 12 and Figures 24 and 25)

In the Courtenay-Comox area, agricultural land use has been present since the first settlers arrived in 1862, but it has decreased in extent in recent times. Marsh habitat was first lost to dyking for agriculture. The naval base at Goose Spit was established in the 1940's (Lyons 1958) and had expanded by 1975. Log storage has been present since at least 1950 on intertidal substrate, subtidal water, and river channel habitat. Residential and industrial areas have increased since 1950. Field's sawmill started operations between 1950 and 1957. The Courtenay Slough marina and two other marinas near the city of Comox have been present since 1950. Intertidal substrate habitat between the two marinas at Comox had been filled by 1975 to create parking. Courtenay Municipal marina had been created from forest by 1964. The sewage lagoon was built on marsh and intertidal substrate habitat in 1962. The airport had been built on meadow and forest habitat by 1975. Today, the main land uses are agricultural, residential, industrial, marinas, airport facilities, a sewage lagoon, and a naval base. Log storage is present, located mainly on subtidal water habitat.

Oyster River/Black Creek (Table 13 and Figures 26 and 27)

At Oyster River, a marina was constructed prior to 1975, destroying marsh and meadow habitat. It had expanded by 1984 through dredging and filling of intertidal substrate habitat. Agricultural and residential land uses have increased over time. Agricultural, residential, and a marina are the main land uses today. No habitat changes have occurred at Black Creek.

Campbell River estuary (Table 14 and Figures 28 and 29)

At the Campbell River estuary, agriculture was present in 1938 but had disappeared by 1965. By 1938, a small log dump and log handling area were present; Elk River Timber Ltd. had been storing logs on the estuary since at least 1938. By 1958, Raven Lumber sawmill was in operation and the dredging of Baikies Slough began. That sawmill has been expanding ever since on upland areas as well as in areas of the slough. Freshwater marina has been present since between 1958 and 1965 and had expanded by 1975. Baikies marina was created by 1975 from a log storage area and had expanded by 1986. Parking facilities adjacent to log handling areas were present by 1965 and by 1986 parking areas for marinas were also present. A bridge was built to the island in Baikies slough between 1965 and 1975. In 1981, the log storage area of

British Columbia Forest Products Ltd. (formerly of Elk River Timber Ltd.) was expanded through dredging and a dryland log sorting facility was created. That facility was established to reduce industrial use of the intertidal zone. A program of marsh development was initiated to compensate for marsh loss (Brownlee et al. 1984; Raymond et al. 1985).

3.2 Major changes in the intertidal zone (Tables 1 to 18)

Marsh

Marsh was lost at 5 estuaries and gained at 2 over the periods of investigation. The greatest net losses were experienced at the Chemainus River, Englishman River, and Courtenay/Comox estuaries. The Cowichan River and Campbell River estuaries were the only sites with net gains. More specifically: Chemainus lost 5 ha to agriculture, Englishman lost 36 ha through construction of 2 dykes but later regained 29 ha through breaching of one of those dykes for a net loss of 7 ha, Courtenay/Comox lost 3 ha through construction of a sewage lagoon, Cowichan lost 8 ha through dyke construction but later regained 23 ha through breaching of 2 dykes for a net gain of 15 ha, and Campbell River lost 1 ha to log handling but regained 3 ha due to marsh transplanting for a net gain of 2 ha.

Over all 14 estuaries and their periods of investigation, marsh habitat experienced no net change in areal extent. That resulted from a balancing of the above losses and gains at different times. The rate of loss per estuary increased from 0 ha/year in the pre-1951 to 1957/58 period to a high of 0.28 ha/year in the period 1962/64/65 to 1975. The reverse was true for the last period, 1975 to 1984/86, when 0.40 ha/year were gained.

The preliminary assessment of the amount of marsh habitat lost to agriculture by dyking (prior to the dates of the earliest air photos) revealed that a total of about 305 ha of marsh was lost in 5 estuaries: the Cowichan (113 ha), Chemainus (34 ha), and Nanaimo (145 ha) river estuaries, Baynes Sound (3 ha), and the Courtenay-Comox area (10 ha). Those 305 ha constitute half of the total amount of marsh remaining in the study sites today (659 ha). Therefore, we estimate that approximately 32% of the original marsh habitat was lost as a result of dyking for agriculture at the turn of the century. That represents the most serious loss of any intertidal habitat type in the study estuaries.

Intertidal Substrate

Intertidal substrate was lost at 9 estuaries and gained in 1 over the periods of investigation. The greatest net losses were experienced at the Nanaimo River, Northwest Bay, Baynes Sound, and Courtenay/Comox estuaries. The Cowichan River estuary was the only site having a net gain. More specifically: Nanaimo lost 17 ha to pulp mill construction and 21 ha to log handling, Northwest Bay lost 5 ha to log handling, Baynes Sound lost 7 ha to log handling and marina construction, Courtenay/Comox lost 9 ha as a result of marina and sewage lagoon construction, and Cowichan gained 1 ha from log handling.

Over all 14 estuaries and their entire periods of investigation, intertidal substrate habitat experienced a net loss of 64 ha at a rate of 1.43 ha/year. The rate of loss per estuary was lowest in the pre-1951 to 1957/58 period at 0.06 ha/year and highest in the period 1957/58 to 1962/64/65 at 0.17 ha/year. The net loss of 64 ha represents only 2% of the total amount of intertidal substrate habitat initially present, however.

Subtidal Water

Subtidal water was lost at 6 estuaries and gained at only 1 over the periods investigated. The greatest net losses occurred at the Cowichan, Chemainus, and Nanaimo river estuaries. The Campbell River estuary was the only site having a net gain. More specifically: Cowichan lost 7 ha, Chemainus lost 14 ha, and Nanaimo lost 19 ha, all to log handling. Campbell River gained 1 ha through dredging.

Over all 14 estuaries and their periods of investigation, subtidal water habitat experienced a net loss of 45 ha at a rate of 1.11 ha/year. The rate of loss per estuary was lowest in the 1957/58 to 1962/64/65 period at 0.01 ha/year and highest in the period 1975 to 1984/86 at 0.16 ha/year. The net loss of 45 ha represents only 2% of the total amount of subtidal water habitat initially present, however.

River Channel and Tide Channel

River channel experienced little change in area over the entire study period; only 1 ha was gained at the Little Qualicum River estuary. No changes in tide channel area were detected.

3.3 Major threats to the intertidal zone

The major threats to intertidal habitats were developments associated with log handling (log sorting areas, log or lumber storage areas on land, sawmills, and log dumps), pulpmills, marinas, and dyking for agriculture.

Log handling activities caused a loss of 79 ha of intertidal habitat in 8 estuaries: 43 ha of subtidal water in 4 estuaries, 34 ha of intertidal substrate in 5 estuaries, and 2 ha of marsh in 2 estuaries. In addition, pulp mill construction caused a loss of 17 ha of intertidal substrate habitat in 1 estuary.

Marina parking caused a loss of 10 ha and marina water a loss of 15 ha in 5 estuaries. Of that total loss of 25 ha, 14 ha of intertidal habitat was involved: 10 ha of intertidal substrate in 5 estuaries, 3 ha of subtidal water in 2 estuaries, and 1 ha of marsh in 1 estuary.

Marsh habitat was lost to agriculture and meadow habitat in 3 estuaries (49 ha) between 1962/64/65 and 1975. Recently (1975-1984/86), marsh habitat was gained from agricultural and meadow habitats (52 ha) by dyke breaching in 2 estuaries.

3.4 Habitat types affected by log storage (Tables 19 to 23)

Log storage was treated separately from the other land uses since the alienated habitat was altered, not lost. The habitat types affected by log storage varied over time. During the dates "prior to 1951", 1957/58 and 1962/64/65, intertidal substrate, subtidal water, tide channels, and river channels were subjected to log storage. Intertidal substrate and subtidal water received the most use. In 1975 and 1984/86, all log storage involved intertidal substrate and subtidal water; storage of logs in the river in the Courtenay-Comox area was the only exception.

Over the period of investigation, the number of estuaries supporting log storage decreased from 11 to 8. The estuaries of the Englishman, Little Qualicum, and Big Qualicum rivers, which had log storage present in 1962/64/65, had none by 1975. The amount of log storage also decreased in 1984/86 at the Campbell and Nanaimo river estuaries, due to the establishment of dryland log sorts, and at Ladysmith Harbour and the Courtenay-Comox area for reasons unknown to us.

3.5 Major changes in the upland zone (Tables 1 to 15)

Because the upper boundary of the zone was chosen arbitrarily, quantitative comparisons are difficult to make. Qualitative changes within each estuary and over all estuaries during the period of investigation are, however, possible.

Forest, meadow, and agricultural land experienced the greatest losses in area, whereas residential, log handling sites, and logged areas experienced the greatest gains. A net loss of 553 ha of forest occurred (14.02 ha/year or 30% of its original area), meadow experienced a loss of 154 ha (4.04 ha/year or 48% of its original area), and agriculture lost 137 ha (3.64 ha/year or 23% of its original area). Residential development increased by 468 ha (13.13 ha/year), log handling sites by 146 ha (3.43 ha/year), and logged areas by 115 ha (2.02 ha/year). Other land uses, such as pulp mills, campsites, industry, parking areas, etc., increased in areal extent as well but not nearly as much as the above.

4. DISCUSSION

4.1 Habitat change

The estimated 32% loss of marsh habitat to agriculture through dyking was the most serious loss of any intertidal habitat type encountered . However, it was lower than other findings in the Pacific Northwest. In the Fraser River estuary, 70% of former salt marsh and 30% of former fresh water tidal marsh were lost to agriculture through dyking (Romaine et al. 1976). In Oregon, 80% of former salt marsh was lost to pasture (Frenkel et al. 1981) and in Washington, 60% of the marshland bordering Puget Sound was lost to dredge and fill projects, jetties, and marinas (Seliskar and Gallagher 1983).

Recent years have seen estuarine marsh losses to log handling developments and marinas but those losses have been increasingly offset by gains through dyke breaching and vegetation transplants, resulting in no net change in marsh extent in the estuaries over the time period investigated. A similar trend was noted in estuaries of Washington, Oregon and northern California: 90% of the documented losses of wetlands occurred prior to the 1930's due to dyking for agriculture. Since then, smaller areas have been lost, due mainly to the dredging and filling associated with port facilities (Boule and Bierly 1987). In British Columbia, marsh gains are expected to continue into the future as estuarine rehabilitation continues to be a focus of attention by environmental conservation agencies.

In contrast to the favourable situation for marshes, losses to intertidal substrate and subtidal water habitats appear to be higher in recent years, both in overall extent and rate of loss. However, the proportion of the total habitat type affected is very low (2%). Pulp mill construction, log handling, and marina development have caused the largest losses to those habitat types, primarily through filling. The areal extent affected by log storage in the intertidal zone has declined in recent years, in part because of new methods of bundling and sorting on dry land.

Land adjacent to estuaries has changed substantially over the period of this study. Increased industrialization and urbanization have been responsible for considerable losses to forest, meadow, and agricultural land.

4.2 Utility of air photos in determining historical habitat change

Air photos provided a useful method for determining historical habitat alienation although there were some problems, as follows:

(a) Air photos were only available for certain years and, unfortunately, those years were not the same for all study sites. Also, since the earliest air photos were taken in 1932, the amount of habitat lost to agriculture before that time could only be estimated.

(b) The scale of air photos ranged from 1:5000 to 1:31680. At the scale of 1:31680, it was difficult to distinguish between certain habitat types (e.g. agriculture from meadow) and it was difficult to determine marsh area. Also, areas of marsh and intertidal substrate could not be accurately calculated from photos taken at high tides. Their locations were determined from other published maps. The identity of some buildings was difficult, so a review of other published sources and ground truthing was necessary.

5. RECOMMENDATIONS

The estuaries investigated are located in one of the most developed areas of the province, an area having a relatively good archive of air photography. No significant losses of marsh, intertidal substrate or subtidal water habitats were noted over the last 40 to 50 years. A full scale study for all

estuaries along the coast of British Columbia is therefore not recommended since those estuaries are sparsely distributed and probably have insufficient historical air photo coverage. However, for certain estuaries where development activities are known to have alienated estuarine habitat (e.g. Fraser, Squamish, and Kitimat river estuaries and Delkatla Slough) a similar study might provide valuable insight into their habitat losses and gains and reasons for those changes.

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Table 1. Area (ha) of intertidal and upland habitat types and land uses at the Cowichan River estuary, 1946 to 1986.

	1946	1957	1962	1975	1986
1. Intertidal:					
1.1 Marsh	86	86	86	78	101
1.2 Intertidal substrate	78	78	78	79	79
1.3 Subtidal water	269	268	268	262	262
1.4 River channel	45	45	45	45	45
1.5 Tide channel					
1.6 Marina water					
2. Upland:					
2.1 Forest	15	15	15	16	18
2.2 Logged					
2.3 Shrub					
2.4 Meadow	3	3	3	3	3
2.5 Agriculture	108	108	108	94	71
2.6 Residential	4	4	4	4	4
2.7 Industrial					
2.8 Log handling		1	1	27	25
2.9 Pulp mill					
2.10 Parking (general)					
2.11 Marina parking					
3. Other:					

Table 2. Area (ha) of intertidal and upland habitat types and land uses at the Chemainus River estuary, 1950 to 1984.

	1950	1957	1962	1975	1984
1. Intertidal:					
1.1 Marsh	126	126	126	121	121
1.2 Intertidal substrate	573	573	573	573	571
1.3 Subtidal water	200	194	192	191	186
1.4 River channel					
1.5 Tide channel					
1.6 Marina water					
2. Upland:					
2.1 Forest	268	258	258	258	258
2.2 Logged					
2.3 Shrub		6	6	6	6
2.4 Meadow	40	13	13	13	13
2.5 Agriculture	136	140	140	144	144
2.6 Residential	17	17	17	17	17
2.7 Industrial					
2.8 Log handling	4				7
2.9 Pulp mill		37	39	41	41
2.10 Parking (general)					
2.11 Marina parking					
3. Other:					

Table 3. Area (ha) of intertidal and upland habitat types and land uses at Ladysmith Harbour, 1950 to 1986.

	1950	1957	1962	1975	1986
1. Intertidal:					
1.1 Marsh	5	5	5	5	5
1.2 Intertidal substrate	111	111	111	110	110
1.3 Subtidal water	28	28	28	28	28
1.4 River channel	2	2	2	2	2
1.5 Tide channel					
1.6 Marina water					
2. Upland:					
2.1 Forest	74	71	70	77	77
2.2 Logged	7	7	7	3	2
2.3 Shrub					1
2.4 Meadow	6	5	3	1	1
2.5 Agriculture	20	18	16	9	10
2.6 Residential		6	9	11	11
2.7 Industrial					
1.8 Log handling			2	7	6
2.9 Pulp mill					
2.10 Parking (general)					
2.11 Marina parking					
3. Other:					

Table 4. Area (ha) of intertidal and upland habitat types and land uses at the Nanaimo River estuary, 1932 to 1986.

	1932	1957	1962	1975	1986
1. Intertidal:					
1.1 Marsh	130	130	130	130	130
1.2 Intertidal substrate	738	728	721	711	700
1.3 Subtidal water	276	276	276	276	257
1.4 River channel	29	29	29	29	29
1.5 Tide channel					
1.6 Marina water					
2. Upland:					
2.1 Forest	271	249	244	226	121
2.2 Logged			5	9	125
2.3 Shrub					
2.4 Meadow	22	22	19	19	19
2.5 Agriculture	125	122	122	122	118
2.6 Residential	20	24	18	27	33
2.7 Industrial	19				
2.8 Log handling		19	29	39	45
2.9 Pulp mill		31	37	42	53
2.10 Parking (general)					
2.10 Marina parking					
3. Other:					

Table 5. Area (ha) of intertidal and upland habitat types and land uses at Nanoose/Bonell Creeks, 1949 to 1984.

	1949	1957	1962	1975	1984
1. Intertidal:					
1.1 Marsh	22	22	22	22	22
1.2 Intertidal substrate	83	83	83	83	83
1.3 Subtidal water					
1.4 River channel					
1.5 Tide channel					
1.6 Marina water					
2. Upland:					
2.1 Forest	40	39	31	31	34
2.2 Logged					
2.3 Shrub	3	3	3	3	1
2.4 Meadow	5	5	2	2	2
2.5 Agriculture	10	10	10	10	9
2.6 Residential	6	7	12	12	12
2.7 Industrial					
2.8 Log handling					
2.9 Pulp mill					
2.10 Parking (general)					
2.11 Marina parking					
3. Other:					
3.1 Church camp			6	6	6

Table 6. Area (ha) of intertidal and upland habitat types and land uses at Northwest Bay, 1949 to 1984.

	1949	1957	1962	1975	1984
1. Intertidal:					
1.1 Marsh					
1.2 Intertidal substrate	27	27	27	22	22
1.3 Subtidal water	154	154	154	151	151
1.4 River channel					
1.5 Tide channel					
1.6 Marina water					
2. Upland:					
2.1 Forest	63	63	63	27	26
2.2 Logged	10	10	10		
2.3 Shrub					
2.4 Meadow					
2.5 Agriculture					
2.6 Residential				29	29
2.7 Industrial					
2.8 Log handling				25	26
2.9 Pulp mill					
2.10 Parking (general)					
2.11 Marina parking					
3. Other:					

Table 7. Area (ha) of intertidal and upland habitat types and land uses at the Englishman River estuary, 1949 to 1984.

	1949	1957	1962	1975	1984
1. Intertidal:					
1.1 Marsh	54	54	54	18	47
1.2 Intertidal substrate	37	37	37	37	37
1.3 Subtidal water	18	18	18	18	18
1.4 River channel					
1.5 Tide channel	3	3	3	3	3
1.6 Marina water					
2. Upland:					
2.1 Forest	34	33	33	31	31
2.2 Logged					
2.3 Shrub					
2.4 Meadow	53	46	46	72	27
2.5 Agriculture					
2.6 Residential		1	1	11	15
2.7 Industrial		6	6	7	7
2.8 Log handling					
2.9 Pulp mill					
2.10 Parking (general)					
2.10 Marina parking					
3. Other:					
3.1 Water canal		1	1	2	2
3.2 Campsite					12

Table 8. Area (ha) of intertidal and upland habitat types and land uses at French Creek, 1949 to 1984.

	1949	1957	1962	1975	1984
1. Intertidal:					
1.1 Marsh	2	2	2	2	2
1.2 Intertidal substrate	5	4	4	4	4
1.3 Subtidal water	23	23	23	22	22
1.4 River channel	2	2	2	2	2
1.5 Tide channel					
1.6 Marina water		1	1	6	6
2. Upland:					
2.1 Forest	21	21	9	8	8
2.2 Logged					
2.3 Shrub					2
2.4 Meadow	25	23	23	18	5
2.5 Agriculture	1	1	1		
2.6 Residential			12	15	25
2.7 Industrial					1
2.8 Log handling					
2.9 Pulp mill					
2.10 Parking (general)					
2.11 Marina parking		2	2	2	2
3. Other:					

Table 9. Area (ha) of intertidal and upland habitat types and land uses at the Little Qualicum River estuary, 1949 to 1984.

	1949	1957	1962	1975	1984
1. Intertidal:					
1.1 Marsh	12	12	11	11	11
1.2 Intertidal substrate	44	44	44	44	44
1.3 Subtidal water					
1.4 River channel	5	5	6	6	6
1.5 Tide channel	1	1	1	1	1
1.6 Marina water					
2. Upland:					
2.1 Forest	20	20	20	20	20
2.2 Logged					
2.3 Shrub	2	2	2	2	2
2.4 Meadow	19	20	20	15	15
2.5 Agriculture	11	11	11	8	8
2.6 Residential	2	2	2	10	10
2.7 Industrial					
2.8 Log handling	1				
2.9 Pulp mill					
2.10 Parking (general)					
2.11 Marina parking					
3. Other:					

Table 10. Area (ha) of intertidal and upland habitat types and land uses at the Big Qualicum River estuary, 1951 to 1984.

	1951	1957	1962	1975	1984
1. Intertidal:					
1.1 Marsh	1	1	1	1	1
1.2 Intertidal substrate	19	19	19	19	19
1.3 Subtidal water					
1.4 River channel	4	4	4	4	4
1.5 Tide channel					
1.6 Marina water					
2. Upland:					
2.1 Forest	13	13	13	13	13
2.2 Logged					
2.3 Shrub				1	1
2.4 Meadow	11	11	11	3	3
2.5 Agriculture					
2.6 Residential					
2.7 Industrial					
2.8 Log handling					
2.9 Pulp mill					
2.10 Parking (general)					
2.11 Marina parking					
3. Other:					
3.1 Campsite				7	7

Table 11. Area (ha) of intertidal and upland habitat types and land uses at Baynes Sound, 1951 to 1984.

	1951	1957	1964	1975	1984
1. Intertidal:					
1.1 Marsh	117	117	117	117	117
1.2 Intertidal substrate	550	550	546	544	543
1.3 Subtidal water	28	28	28	28	28
1.4 River channel					
1.5 Tide channel					
1.6 Marina water			1	1	1
2. Upland:					
2.1 Forest	647	622	622	461	442
2.2 Logged		12			
2.3 Shrub	3	3	3	16	16
2.4 Meadow	24	24	27	27	26
2.5 Agriculture	19	19	26	29	29
2.6 Residential	26	46	49	196	212
2.7 Industrial	14	7	7	3	3
2.8 Log handling			2	5	10
2.9 Pulp mill					
2.10 Parking (general)					
2.11 Marina parking					
3. Other:					
3.1 Warf/weir				1	1

Table 12. Area (ha) of intertidal and upland habitat types and land uses at the Courtenay/Comox area, 1950 to 1986.

	1950	1957	1964	1975	1986
1. Intertidal:					
1.1 Marsh	77	77	74	74	74
1.2 Intertidal substrate	430	428	424	421	421
1.3 Subtidal water	870	868	868	868	868
1.4 River channel	35	35	35	35	35
1.5 Tide channel					
1.6 Marina water	1	5	5	5	5
2. Upland:					
2.1 Forest	139	110	96	91	87
2.2 Logged					2
2.3 Shrub	6	6	6	6	6
2.4 Meadow	48	45	41	33	30
2.5 Agriculture	122	35	35	24	22
2.6 Residential	13	130	141	145	143
2.7 Industrial	1	1	8	20	26
2.8 Log handling		2	2	2	5
2.9 Pulp mill					
2.10 Parking (general)					
2.11 Marina parking			1	5	5
3. Other:					
3.1 Airport				6	6
3.2 Sewage lagoon			6	6	6
3.3 Naval base	9	9	9	10	10

Table 13. Area (ha) of intertidal and upland habitat types and land uses at Oyster River and Black Creek, 1938 to 1984.

	1938	1957	1962	1975	1984
1. Intertidal:					
1.1 Marsh	4	4	4	3	3
1.2 Intertidal substrate	65	65	65	65	64
1.3 Subtidal water	15	15	15	15	15
1.4 River channel	5	5	5	5	5
1.5 Tide channel					
1.6 Marina water				1	1
2. Upland:					
2.1 Forest	102	91	91	76	75
2.2 Logged					
2.3 Shrub		7	7		
2.4 Meadow	17	4	4	3	1
2.5 Agriculture	7	7	7	18	18
2.6 Residential		17	17	27	30
2.7 Industrial					
2.8 Log handling					
2.9 Pulp mill					
2.10 Parking (general)					
2.11 Marina parking				2	3
3. Other:					

Table 14. Area (ha) of intertidal and upland habitat types and land uses at the Campbell River estuary, 1938 to 1986.

	1938	1958	1965	1975	1986
1. Intertidal:					
1.1 Marsh	23	23	23	22	25
1.2 Intertidal substrate	30	31	32	33	29
1.3 Subtidal water	7	7	7	8	8
1.4 River channel	23	23	23	23	23
1.5 Tide channel					
1.6 Marina water			<1	2	3
2. Upland:					
2.1 Forest	149	120	112	104	93
2.2 Logged	1	19	24	6	4
2.3 Shrub			2	18	20
2.4 Meadow	45	38	35	27	19
2.5 Agriculture	7	5			
2.6 Residential	1	14	17	18	16
2.7 Industrial		2	3	9	14
2.8 Log handling	<1	4	6	14	27
2.9 Pulp mill					
2.10 Parking (general)			2	2	5
2.11 Marina parking					
3. Other:					

Table 15. Losses, gains (ha) and rates of change (ha/year in brackets) of intertidal and upland habitat types and land uses in 14 estuaries on the east coast of Vancouver Island, from (pre-) 1951 to (post-) 1984.

	Cowichan River (1946-1986)	Chemainus River (1950-1984)	Ladysmith Harbour (1950-1986)	Nanaimo River (1932-1986)	Nanoose/Bonell Creeks (1949-1984)	Northwest Bay (1949-1984)	Englishman River (1949-1984)	French Creek (1949-1984)
1. Intertidal:								
1.1 Marsh	+15 (.38)	-5 (.15)					-7 (.20)	
1.2 Intertidal substrate	+1 (.03)	-2 (.06)	-1 (.03)	-38 (.70)		-5 (.14)		-1 (.03)
1.3 Subtidal water	-7 (.18)	-14 (.41)		-19 (.35)		-3 (.09)		-1 (.03)
1.4 River channel								
1.5 Tide channel								
1.6 Marina water								+6 (.17)
2. Upland:								
2.1 Forest	+3 (.07)	-10 (.29)	+3 (.08)	-150 (2.78)	-6 (.17)	-37 (1.06)	-3 (.09)	-13 (.37)
2.2 Logged			-5 (.14)	+125 (2.32)		-10 (.28)		
2.3 Shrub		+6 (.17)	+1 (.03)		-2 (.06)			+2 (.06)
2.4 Meadow		-27 (.79)	-5 (.14)	-3 (.06)	-3 (.08)		-26 (.74)	-20 (.57)
2.5 Agriculture	-37 (.93)	+8 (.24)	-10 (.28)	-7 (.13)	-1 (.03)			-1 (.03)
2.6 Residential			+11 (.31)	+13 (.24)	+6 (.17)	+29 (.83)	+15 (.43)	+25 (.71)
2.7 Industrial				-19 (.35)			+7 (.20)	+1 (.03)
2.8 Log handling	+25 (.63)	+3 (.09)	+6 (.17)	+45 (.83)		+26 (.74)		
2.9 Pulp mill (incl. dock)		+41 (1.20)		+53 (.98)				
2.10 Parking (general)								
2.11 Marina parking								+2 (.06)
2.12 Campsite							+12 (.34)	
2.13 Church camp					+6 (.17)			
2.14 Airport								
3. Other:								
3.1 Sewage lagoon								
3.2 Naval base								
3.3 Water canal							+2 (.06)	
3.4 Weir/warf								

Table 15. continued

	Little Qualicum River (1949-1984)		Big Qualicum River (1951-1984)		Baynes Sound (1951-1984)		Courtenay/ Comox area (1950-1986)		Oyster River and Black Creek (1938-1984)		Campbell River (1938-1986)		Summary: all estuaries	
1. Intertidal:														
1.1 Marsh	-1	(.03)					-3	(.09)	-1	(.02)	+2	(.04)	0	(0)
1.2 Intertidal substrate					-7	(.21)	-9	(.25)	-1	(.02)	-1	(.02)	-64	(1.43)
1.3 Subtidal water							-2	(.06)			+1	(.02)	-45	(1.11)
1.4 River channel	+1	(.03)											+1	(.03)
1.5 Tide channel													0	(0)
1.6 Marina water					+1	(.03)	+4	(.11)	+1	(.02)	+3	(.06)	+15	(.39)
2. Upland:														
2.1 Forest					-205	(6.21)	-52	(1.45)	-27	(.59)	-56	(1.16)	-553	(14.02)
2.2 Logged							+2	(.06)			+3	(.06)	+115	(2.02)
2.3 Shrub			+1	(.03)	+13	(.39)					+20	(.42)	+41	(1.04)
2.4 Meadow	-4	(.11)	-8	(.24)	+2	(.06)	-18	(.50)	-16	(.33)	-26	(.54)	-154	(4.04)
2.5 Agriculture	-3	(.09)			+10	(.30)	-100	(2.78)	+11	(.23)	-7	(.14)	-137	(3.64)
2.6 Residential	+8	(.23)			+186	(5.64)	+130	(3.61)	+30	(.65)	+15	(.31)	+468	(13.13)
2.7 Industrial					-11	(.33)	+25	(.70)			+14	(.29)	+17	(.54)
2.8 Log handling	-1	(.03)			+10	(.30)	+5	(.14)			+27	(.56)	+146	(3.43)
2.9 Pulp mill (incl. dock)													+94	(2.18)
2.10 Parking (general)											+5	(.10)	+5	(.10)
2.11 Marina parking							+5	(.14)	+3	(.06)			+10	(.26)
2.12 Campsite			+7	(.21)									+19	(.55)
2.13 Church camp													+6	(.17)
2.14 Airport							+6	(.17)					+6	(.17)
3. Other:														
3.1 Sewage lagoon							+6	(.17)					+6	(.17)
3.2 Naval base							+1	(.03)					+1	(.03)
3.3 Water canal													+2	(.06)
3.4 Weir/warf					+1	(.03)							+1	(.03)

Table 16. Details regarding losses, gains (ha) and rates of change (ha/year in brackets) of marsh habitat in 14 estuaries on the east coast of Vancouver Island, from (pre-) 1951 to (post-) 1984 (see Tables 1-14 for exact time periods).

	pre- 1951 to 1957/58	1957/58 to 1962/64/65	1962/64/65 to 1975	1975 to 1984/86
Cowichan River			-8 (.62) lost to agriculture by dyke building.	+23 (2.09) gained from agriculture by dyke breaching
Chemainus River			-5 (.38) lost to agriculture	
Ladysmith Harbour				
Nanaimo River				
Nanoose/Bonell Creeks				
Northwest Bay				
Englishman River			-36 (2.77) lost to meadow by dyke building	+29 (3.22) gained from meadow by dyke breaching
French Creek				
Little Qualicum River		-1 (.20) lost to log handling		
Big Qualicum River				
Baynes Sound				
Courtenay/Comox area		-3 (.43) lost to sewage lagoon		
Oyster River and Black Creek			-1 (.08) lost to marina	
Campbell River			-1 (.10) lost to log handling	+3 (.27) marsh transplanting for rehabilitation
Total (mean)		-4 (.05)	-51 (.28)	+55 (.40)

Table 17. Details regarding losses, gains (ha) and rates of change (ha/year in brackets) of intertidal substrate habitat in 14 estuaries on the east coast of Vancouver Island, from (pre-) 1951 to (post-) 1984 (see Tables 1-14 for exact time periods).

	pre- 1951 to 1957/58	1957/58 to 1962/64/65	1962/64/65 to 1975	1975 to 1984/86
Cowichan River			+1 (.08) loss and gain to log handling	
Chemainus River				-2 (.22) to log handling
Ladysmith Harbour			-1 (.08) to log handling	
Nanaimo River	-10 (.40) to pulp mill	-7 (1.4) to pulp mill	-10 (.77) to log handling	-11 (1.0) to log handling
Nanoose/Bonell Creeks				
Northwest Bay			-5 (.38) to log handling	
Englishman River				
French Creek	-1 (.13) to marina			
Little Qualicum River				
Big Qualicum River				
Baynes Sound		-4 (.57) to marina and log handling	-2 (.18) to log handling and weir/wharf	-1 (.11) to log handling
Courtenay/Comox area	-2 (. 29) to marina	-4 (.57) to sewage lagoon and marina	-3 (.27) to marina	
Oyster River and Black Creek				-1 (.11) to marina
Campbell River	+1 (.05) to log handling	+1 (.14) to log handling	+1 (.10) gain to log handling, loss to marina	-4 (.36) loss to marsh re-habilitation, marina and log handling; gain to log handling
Total (mean)	-12 (.06)	-14 (.17)	-19 (.11)	-19 (.13)

Table 18. Details regarding losses, gains (ha) and rates of change (ha/year in brackets) of subtidal water (and river channel habitat in the Little Qualicum River estuary only) in 14 estuaries on the east coast of Vancouver Island, from (pre-) 1951 to (post-) 1984 (see Tables 1-14 for exact time periods).

	pre- 1951 to 1957/58	1957/58 to 1962/64/65	1962/64/65 to 1975	1975 to 1984/86
Cowichan River	-1 (.09) to log handling		-6 (.46) to log handling	
Chemainus River	-6 (.86) to log handling	-2 (.40) to log handling	-1 (.08) to log handling	-5 (.56) to log handling
Ladysmith Harbour				
Nanaimo River				-19 (1.73) to log handling
Nanoose/Bonell Creeks				
Northwest Bay			-3 (.23) to log handling	
Englishman River				
French Creek			-1 (.08) to marina	
Little Qualicum River (river channel)		+1 (.20) to log handling		
Big Qualicum River				
Baynes Sound				
Courtenay/Comox area	-2 (.29) to marina			
Oyster River and Black Creek				
Campbell River			+1 (.10) marsh dredged	
Total (mean)	-9 (.09)	-1 (.01)	-10 (.05)	-24 (.16)

Table 19. Area (ha) of habitat types affected by log storage in 14 estuaries on the east coast of Vancouver Island, "prior to 1951".

	Intertidal substrate	Subtidal water	Tide channel	River channel
Cowichan River		7		
Chemainus River	14	10		
Ladysmith Harbour	4			
Nanaimo River				
Nanoose/Bonell Creeks				
Northwest Bay	9	7		
Englishman River			3	
French Creek				
Little Qualicum River			1	
Big Qualicum River				1
Baynes Sound	8	10		
Courtenay/Comox area	16	10		
Oyster River and Black Creek				
Campbell River	19	4		
Total	70	48	4	1

Table 20. Area (ha) of habitat types affected by log storage in 14 estuaries on the east coast of Vancouver Island, 1957 or 1958.

	Intertidal substrate	Subtidal water	Tide channel	River channel
Cowichan River		72		
Chemainus River	12			
Ladysmith Harbour	3			
Nanaimo River	90			
Nanoose/Bonell Creeks				
Northwest Bay	6	16		
Englishman River			1	
French Creek				
Little Qualicum River				
Big Qualicum River				1
Baynes Sound	6	13		
Courtenay/Comox area	1	9		1
Oyster River and Black Creek				
Campbell River	22			
Total	140	110	1	2

Table 21. Area (ha) of habitat types affected by log storage in 14 estuaries on the east coast of Vancouver Island, 1962, 1964 or 1965.

	Intertidal substrate	Subtidal water	Tide channel	River channel
Cowichan River		89		
Chemainus River	19	8		
Ladysmith Harbour	1			
Nanaimo River	135			
Nanoose/Bonell Creeks				
Northwest Bay	7	14		
Englishman River			<1	
French Creek				
Little Qualicum River				1
Big Qualicum River				1
Baynes Sound	3	8		
Courtenay/Comox area	4	14		
Oyster River and Black Creek				
Campbell River	16			
Total	185	133	<1	2

Table 22. Area (ha) of habitat types affected by log storage in 14 estuaries on the east coast of Vancouver Island, 1975.

	Intertidal substrate	Subtidal water	Tide channel	River channel
Cowichan River		45		
Chemainus River	43	23		
Ladysmith Harbour	20	3		
Nanaimo River	175			
Nanoose/Bonell Creeks				
Northwest Bay	1	5		
Englishman River				
French Creek				
Little Qualicum River				
Big Qualicum River				
Baynes Sound	6			
Courtenay/Comox area	1	8		1
Oyster River and Black Creek				
Campbell River	22			
Total	268	84		1

Table 23. Area (ha) of habitat types affected by log storage in 14 estuaries on the east coast of Vancouver Island, 1984 or 1986.

	Intertidal substrate	Subtidal water	Tide channel	River channel
Cowichan River	1	61		
Chemainus River	33	33		
Ladysmith Harbour	3			
Nanaimo River	33			
Nanoose/Bonell Creeks				
Northwest Bay	1	4		
Englishman River				
French Creek				
Little Qualicum River				
Big Qualicum River				
Baynes Sound	2	2		
Courtenay/Comox area		3		
Oyster River and Black Creek				
Campbell River	6			
Total	79	103		

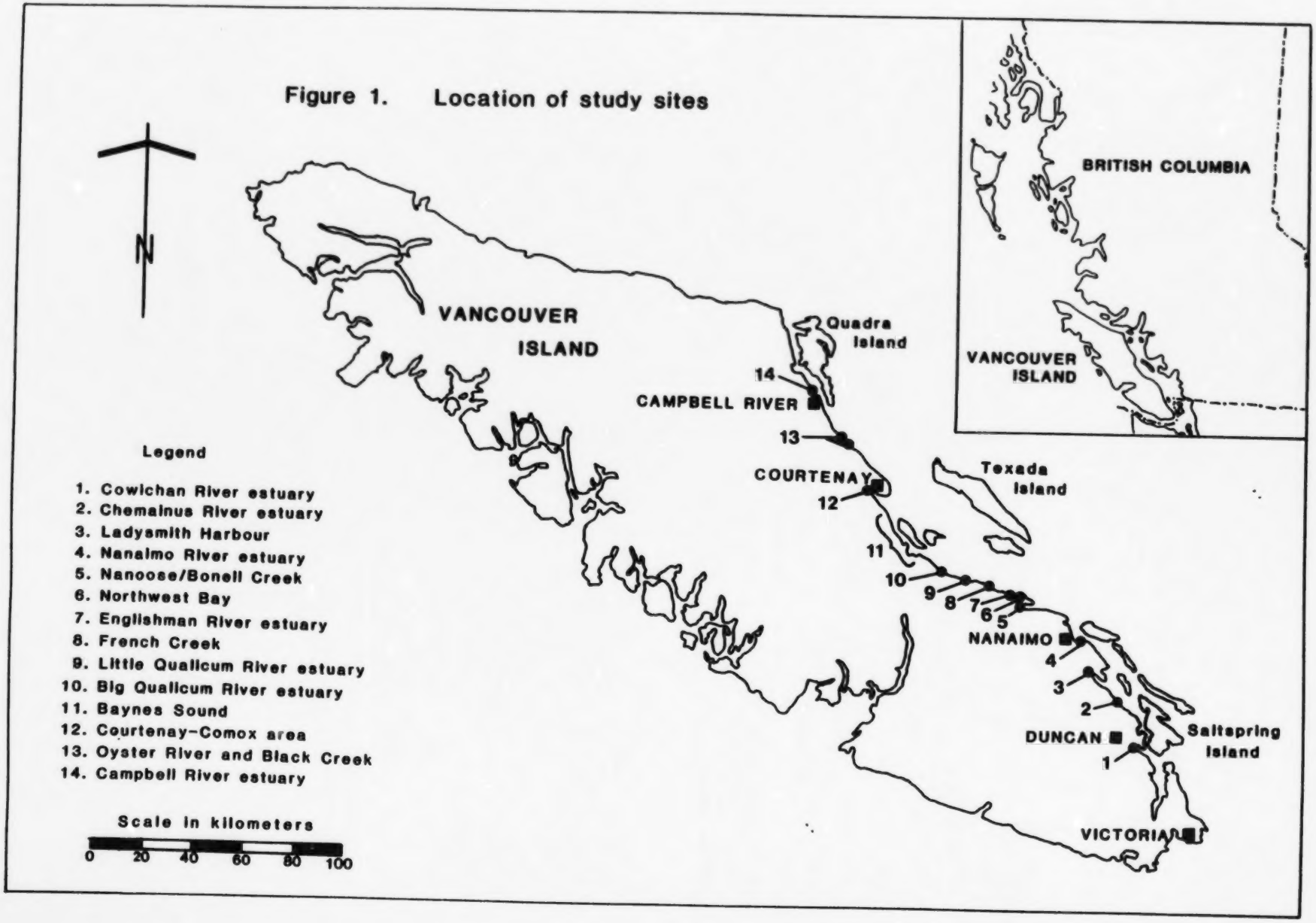


Figure 1. Location of study sites
N
VANCOUVER ISLAND
Quadra Island
14
CAMPBELL RIVER
13
COURTENAY
12
Texada Island
11
10
9
8
7
6
5
NANAIMO
4
3
2
DUNCAN
1
Saltspring Island
VICTORIA
BRITISH COLUMBIA
VANCOUVER ISLAND
Legend
1. Cowichan River estuary
2. Chemainus River estuary
3. Ladysmith Harbour
4. Nanaimo River estuary
5. Nanoose/Bonell Creek
6. Northwest Bay
7. Englishman River estuary
8. French Creek
9. Little Qualicum River estuary
10. Big Qualicum River estuary
11. Baynes Sound
12. Courtenay-Comox area
13. Oyster River and Black Creek
14. Campbell River estuary
Scale in kilometers
0 20 40 60 80 100

Figure 2. Map of the Cowichan River estuary in 1946.

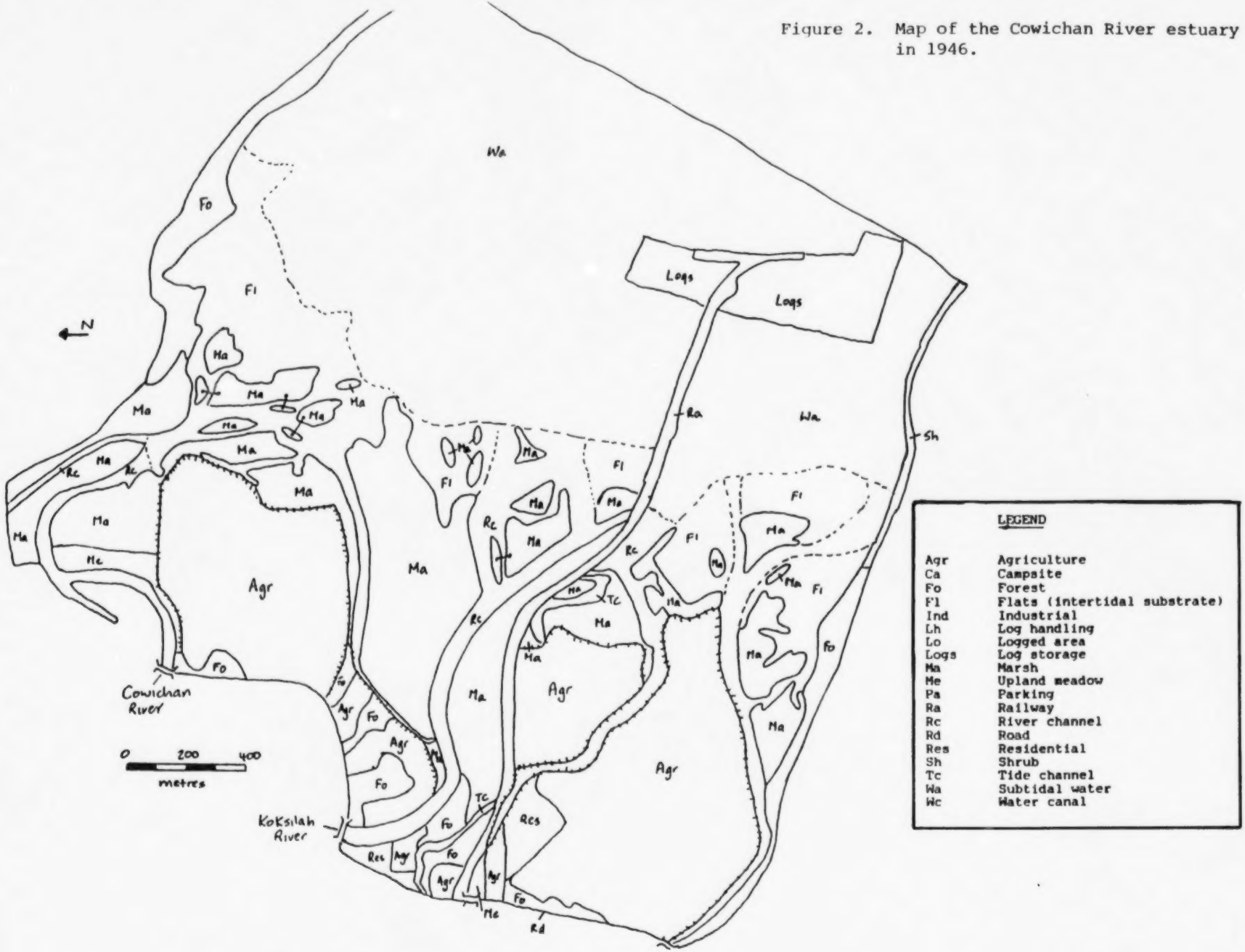
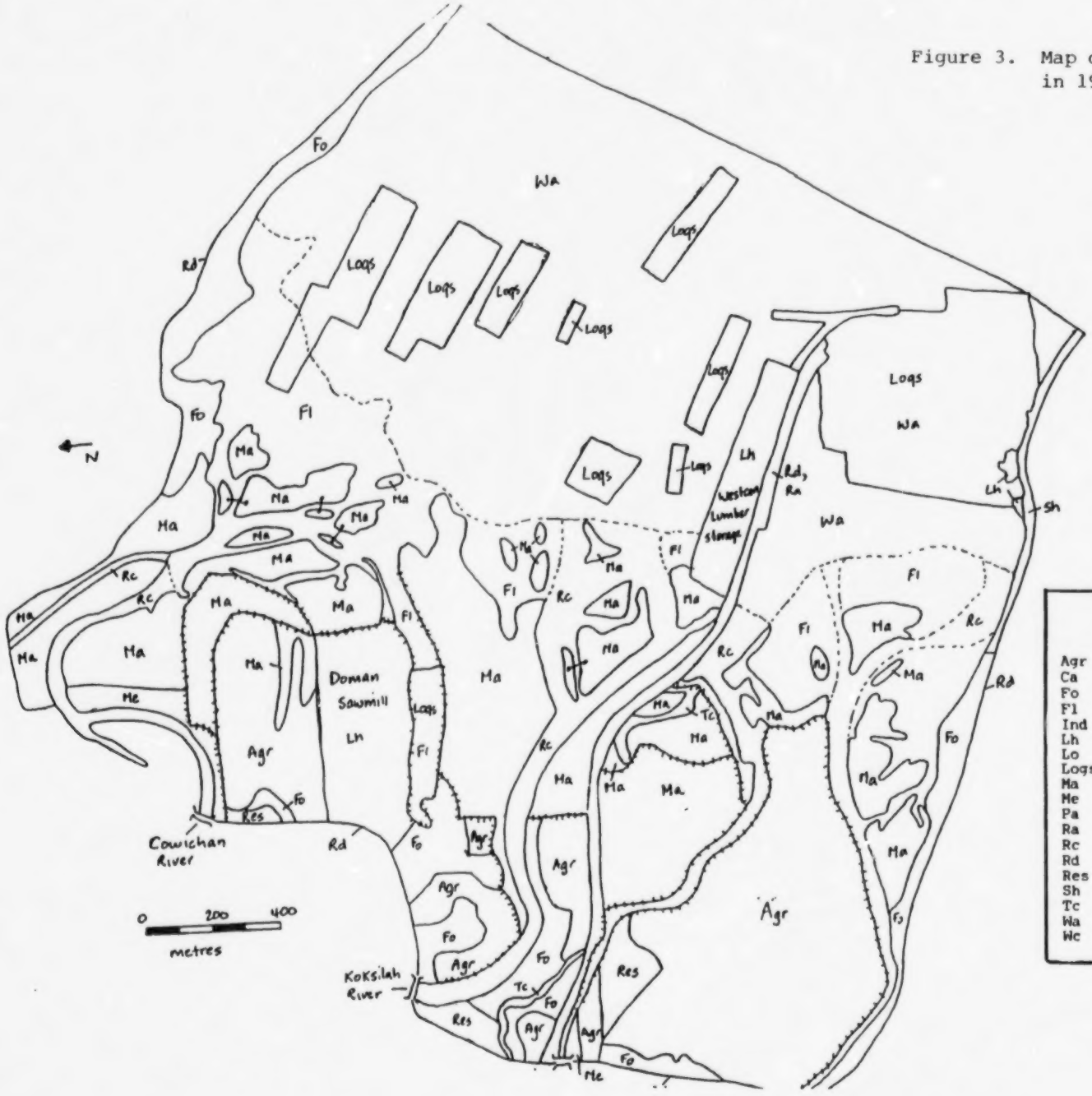


Figure 3. Map of the Cowichan River estuary in 1986.



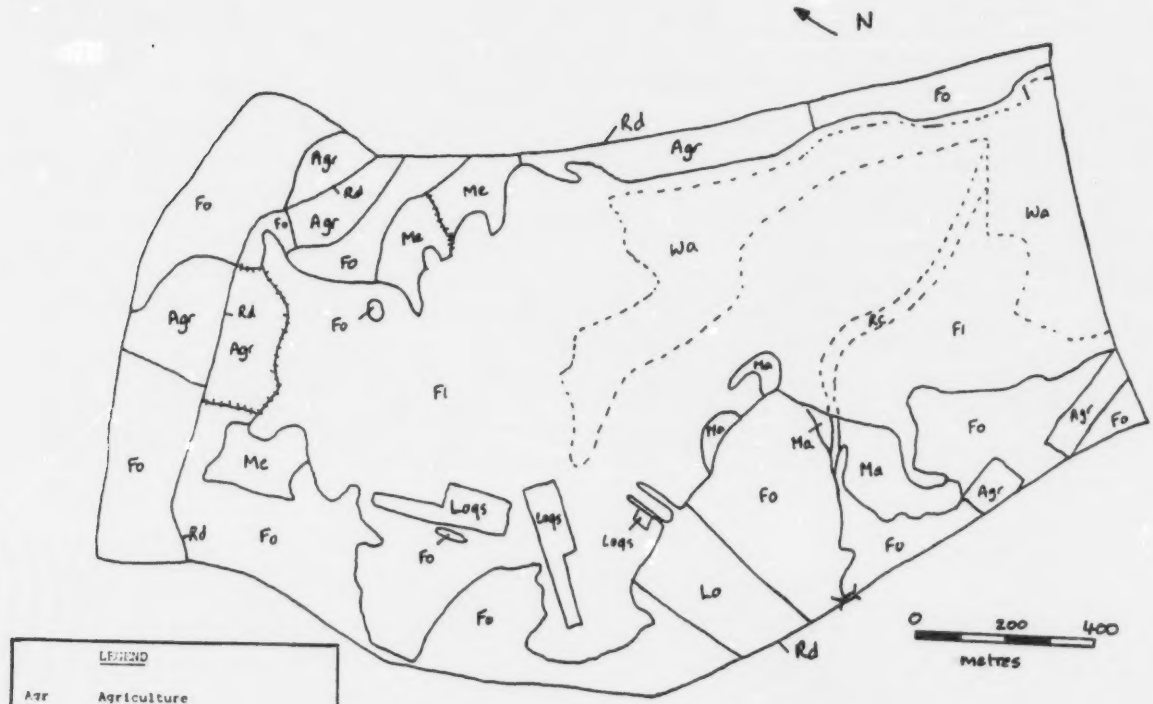
LEGEND

Agr	Agriculture
Ca	Campsite
Fo	Forest
Fl	Flats (intertidal substrate)
Ind	Industrial
Lh	Log handling
Lo	Logged area
Logs	Log storage
Ma	Marsh
Me	Upland meadow
Pa	Parking
Ra	Railway
Rc	River channel
Rd	Road
Res	Residential
Sh	Shrub
Tc	Tide channel
Wa	Subtidal water
Wc	Water canal

Figure 4. Map of the Chemainus River estuary in 1950.

Figure 5. Map of the Chemainus River estuary in 1984.

Figure 6. Map of Ladysmith Harbour in 1950.



LEGEND

Agr	Agriculture
Ca	Campsite
Fo	Forest
Fl	Flats (intertidal substrate)
Ind	Industrial
Lh	Log handling
Lo	Logged area
Logs	Log storage
Ma	Marsh
Me	Upland meadow
Pa	Parking
Ra	Railway
Rc	River channel
Rd	Road
Res	Residential
Sh	Shrub
Tc	Tide channel
Wa	Subtidal water
Wc	Water canal

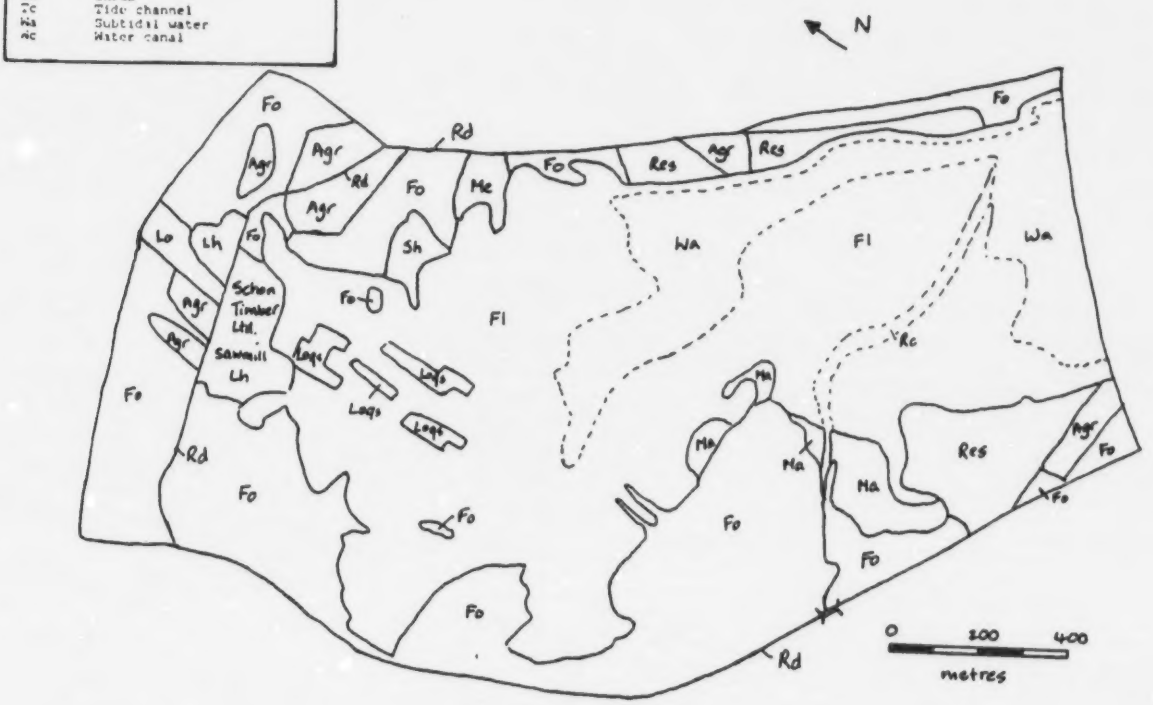


Figure 7. Map of Ladysmith Harbour in 1986.

Figure 8. Map of the Nanaimo River estuary in 1932.

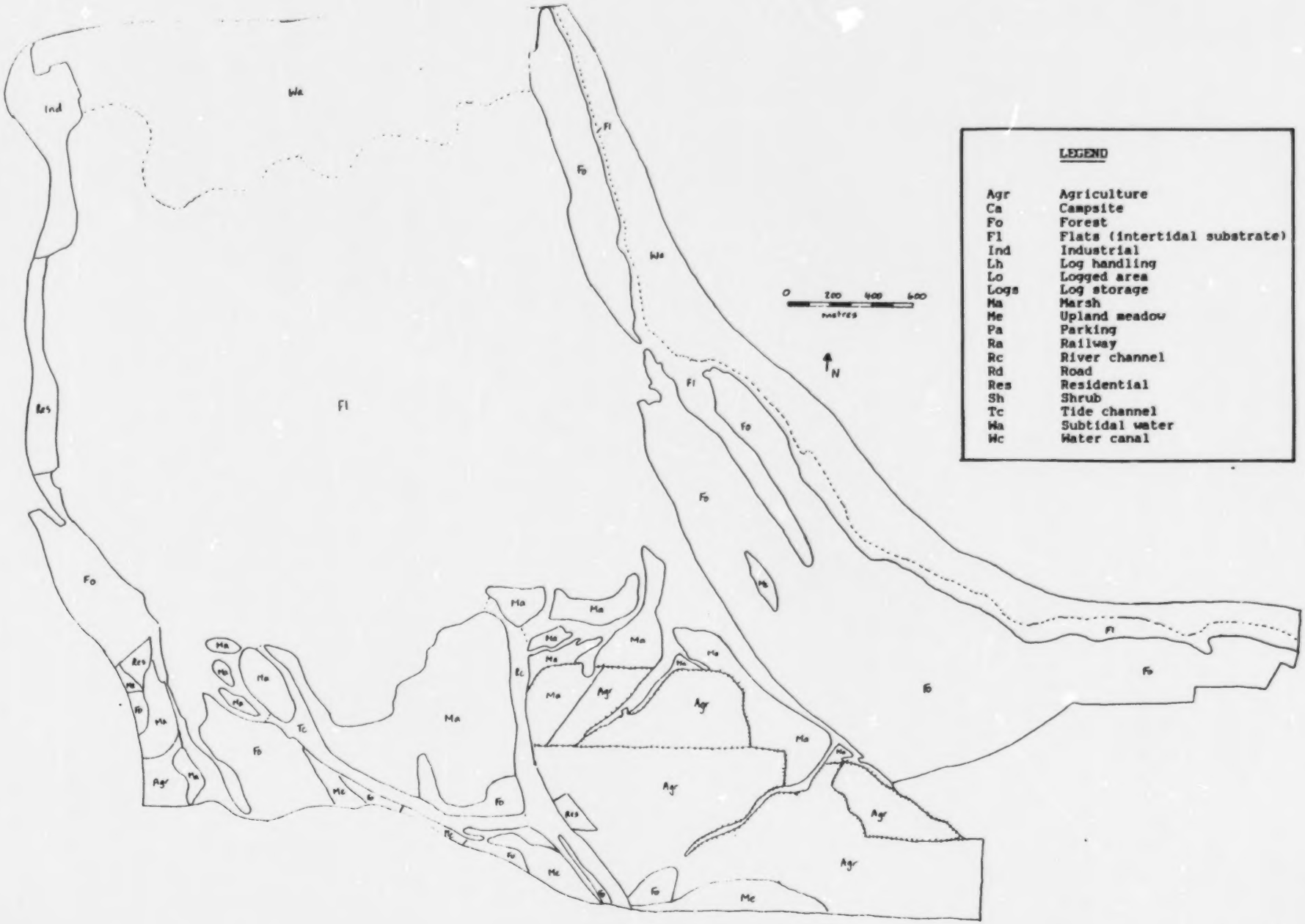


Figure 9. Map of the Nanaimo River estuary in 1986.

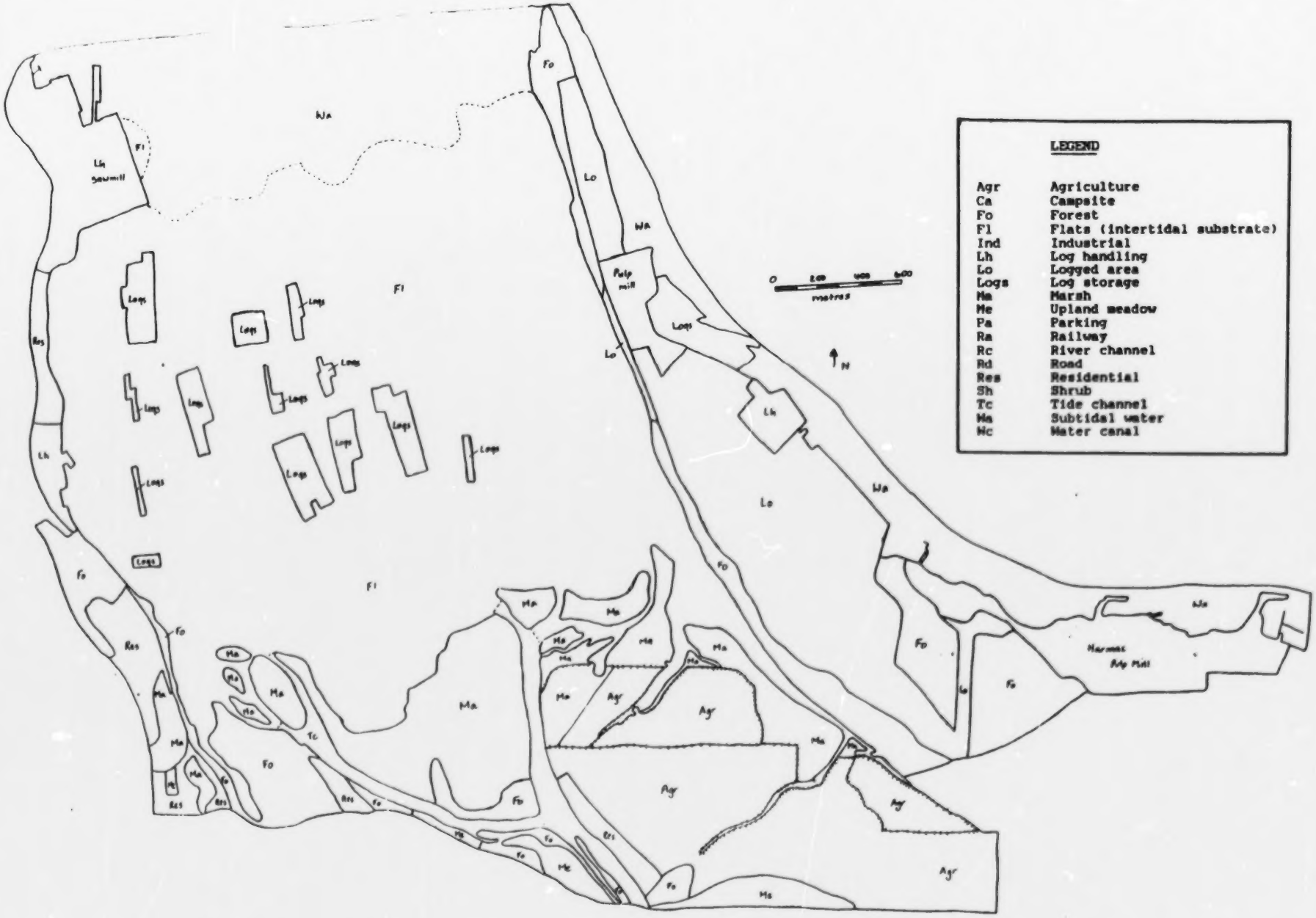
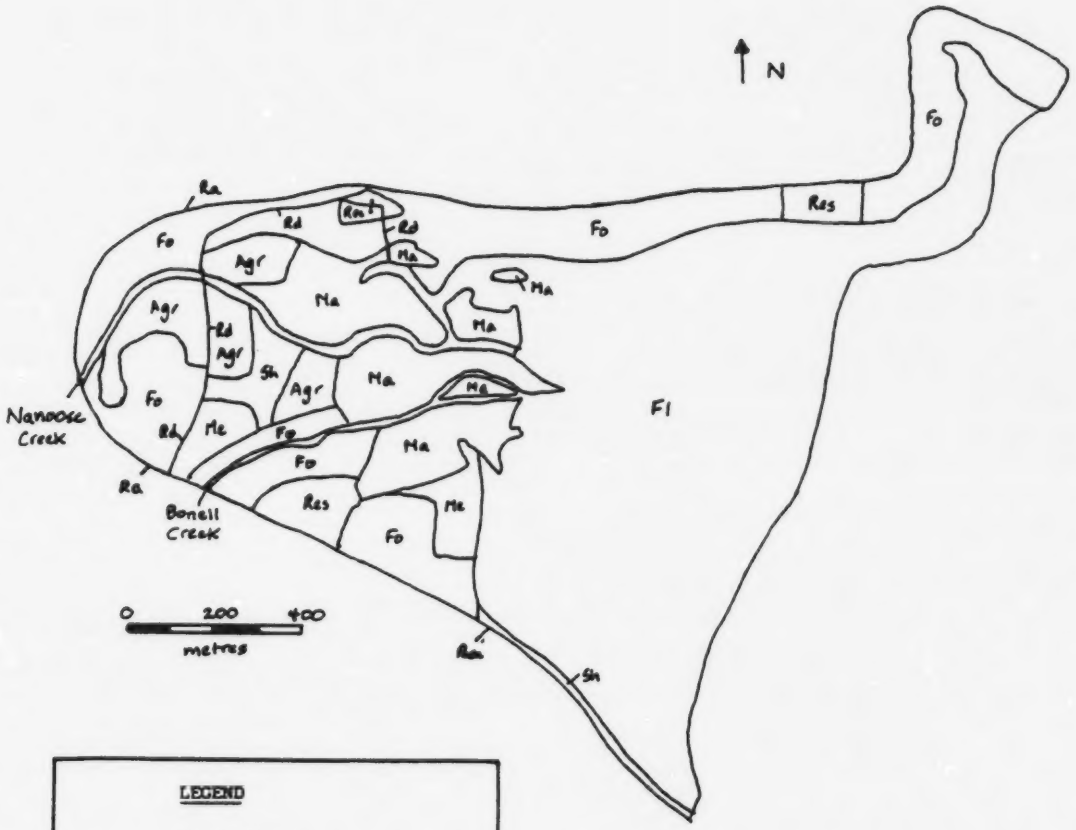


Figure 10. Map of Nanoose/Bonell Creeks in 1949.



LEGEND

Agr	Agriculture
Ca	Campsite
Fo	Forest
Fl	Flats (intertidal substrate)
Ind	Industrial
Lh	Log handling
Lo	Logged area
Logs	Log storage
Ma	Marsh
Me	Upland meadow
Pa	Parking
Ra	Railway
Rc	River channel
Rd	Road
Res	Residential
Sh	Shrub
Tc	Tide channel
Wa	Subtidal water
Wc	Water canal

Figure 11. Map of Nanoose/Bonell Creeks in 1984.

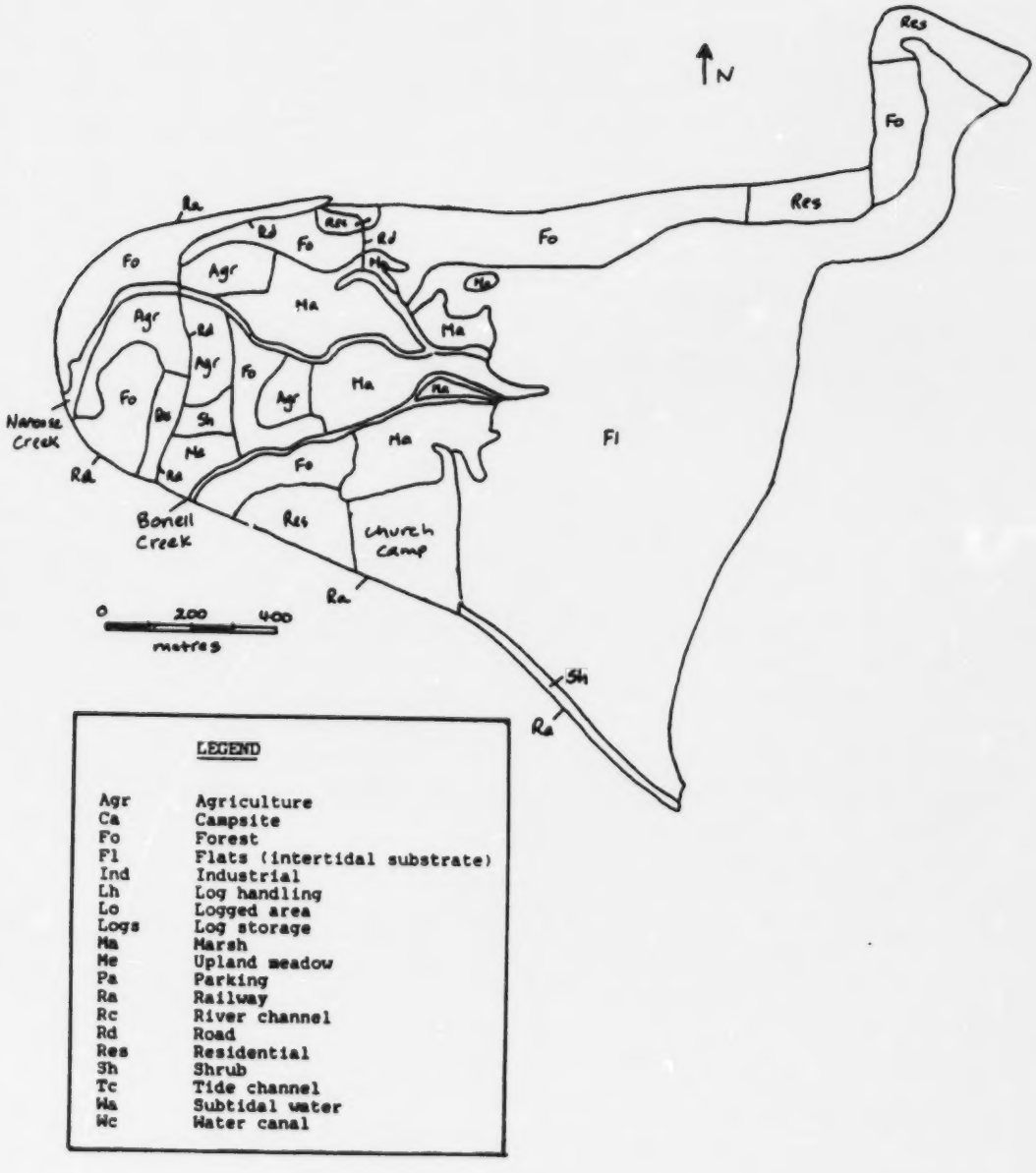
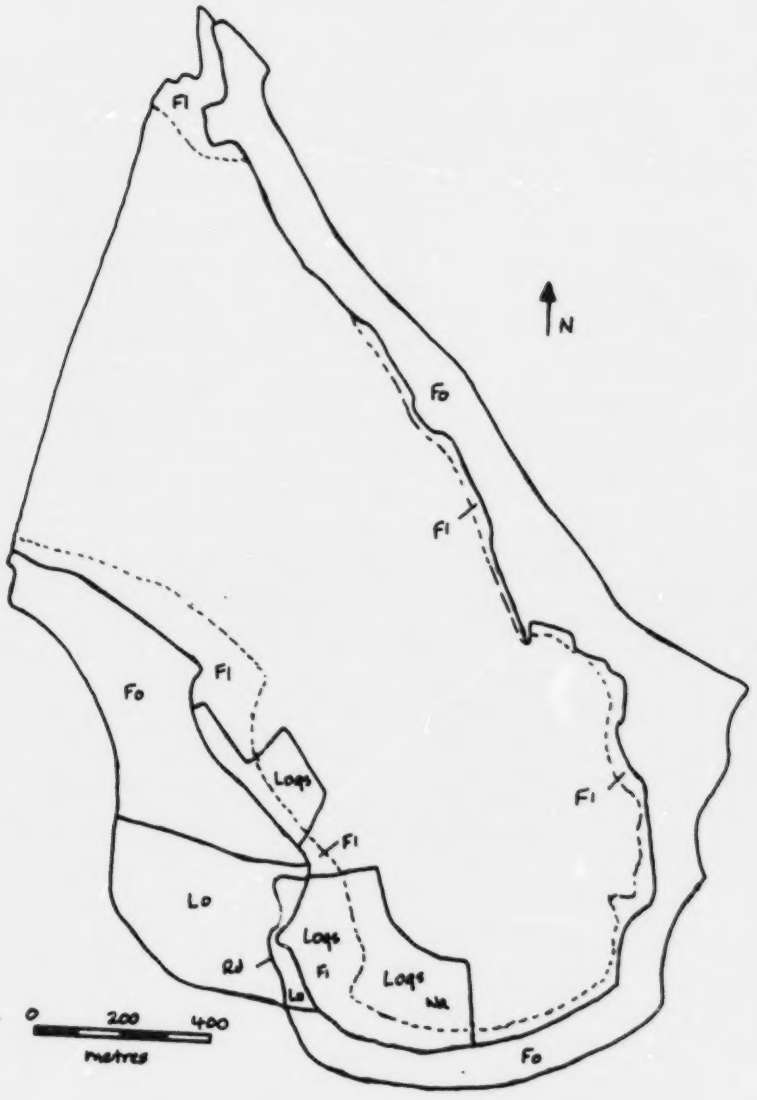


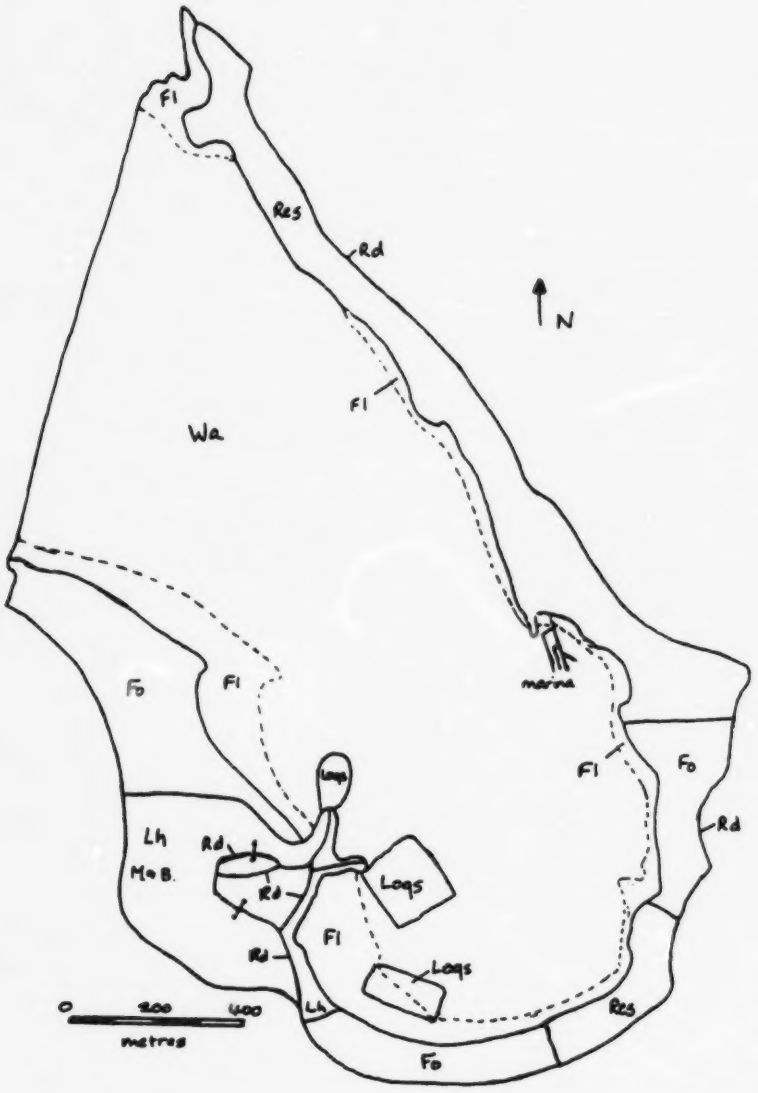
Figure 12. Map of Northwest Bay in 1949.



LEGEND

Agr	Agriculture
Ca	Campsite
Fo	Forest
Fl	Flats (intertidal substrate)
Ind	Industrial
Lh	Log handling
Lo	Logged area
Logs	Log storage
Ma	Marsh
Me	Upland meadow
Pa	Parking
Ra	Railway
Rc	River channel
Rd	Road
Res	Residential
Sh	Shrub
Tc	Tide channel
Wa	Subtidal water
Wc	Water canal

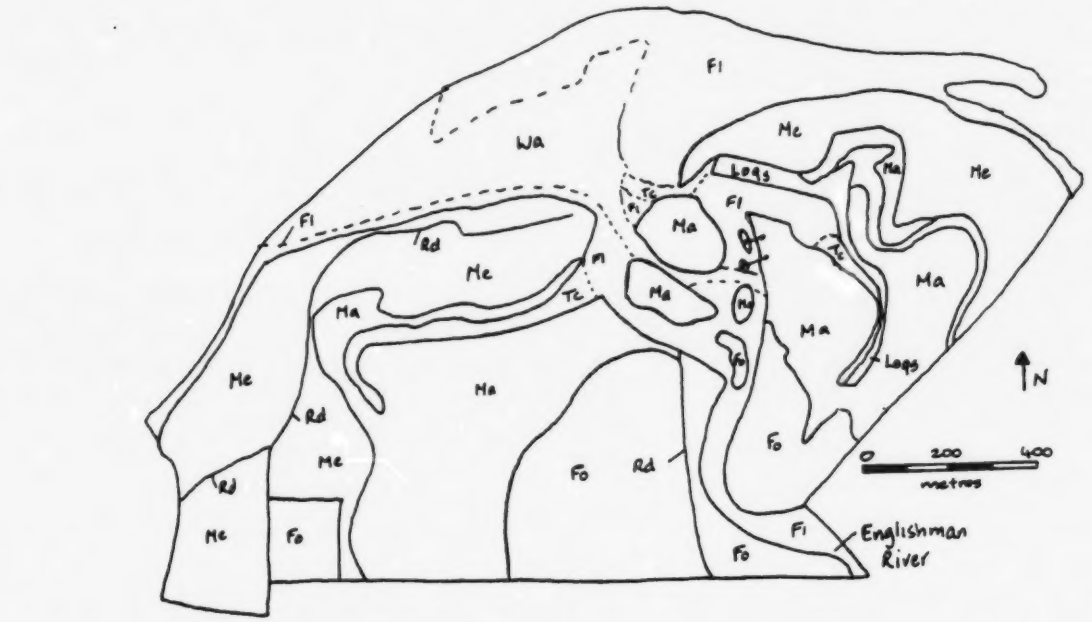
Figure 13. Map of Northwest Bay in 1984.



LEGEND

Agr	Agriculture
Ca	Campsite
Fo	Forest
Fl	Flats (intertidal substrate)
Ind	Industrial
Lh	Log handling
Ls	Logged area
Logs	Log storage
Mh	Marsh
Mo	Upland meadow
Pa	Parking
Ra	Railway
Rc	River channel
Rd	Road
Res	Residential
Sh	Shrub
Tc	Tide channel
Wa	Subtidal water
Wc	Water canal

Figure 14. Map of Englishman River estuary in 1949.



LEGEND

Agr	Agriculture
Ca	Campsite
Fo	Forest
Fl	Flats (intertidal substrate)
Ind	Industrial
Lh	Log handling
Lo	Logged area
Logs	Log storage
Ma	Marsh
Me	Upland meadow
Pa	Parking
Ra	Railway
Rc	River channel
Rd	Road
Res	Residential
Sh	Shrub
Tc	Tide channel
Wa	Subtidal water
wc	Water canal

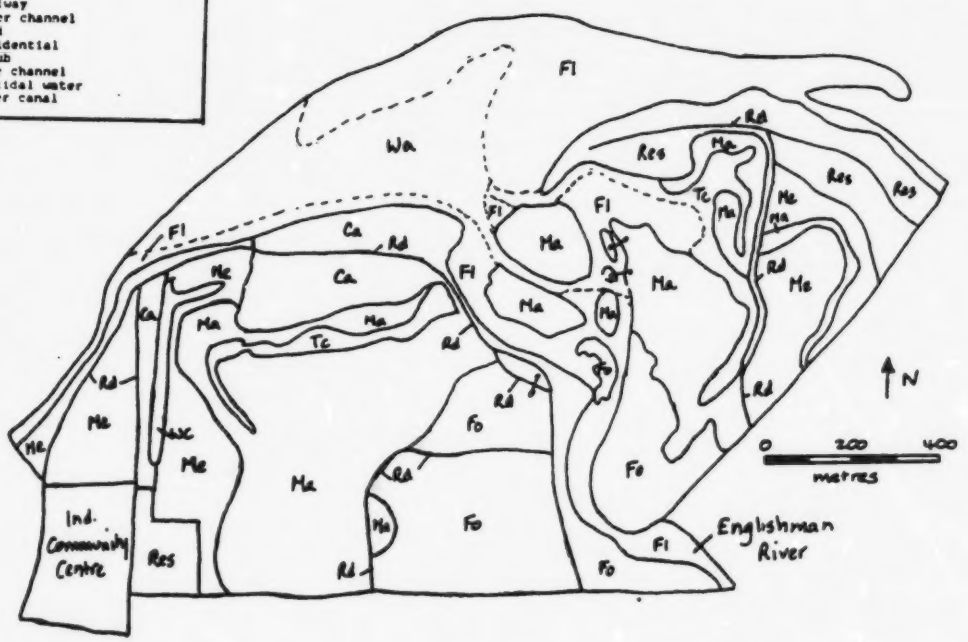
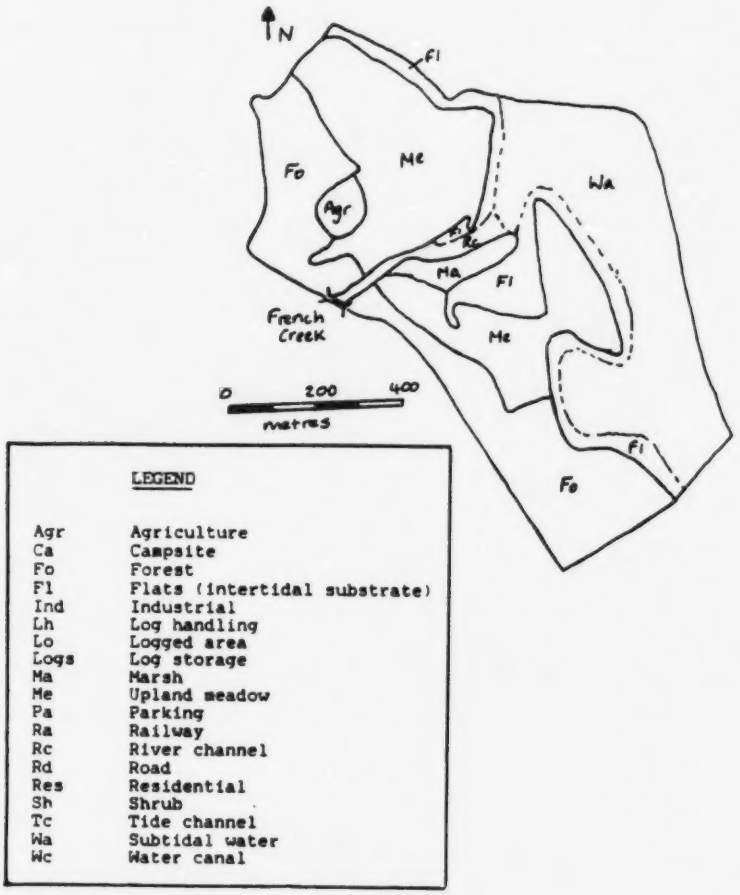


Figure 15. Map of Englishman River estuary in 1984.

Figure 16. Map of French Creek in 1949.



LEGEND

Agr	Agriculture
Ca	Campsite
Fo	Forest
Fl	Flats (intertidal substrate)
Ind	Industrial
Lh	Log handling
Lo	Logged area
Logs	Log storage
Ma	Marsh
Me	Upland meadow
Pa	Parking
Ra	Railway
Rc	River channel
Rd	Road
Res	Residential
Sh	Shrub
Tc	Tide channel
Wa	Subtidal water
Wc	Water canal

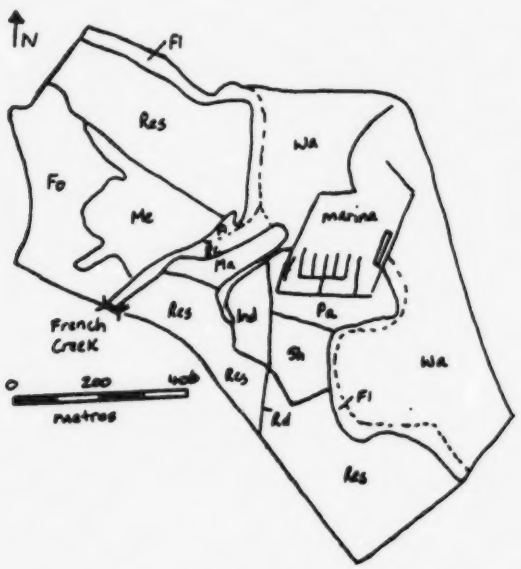
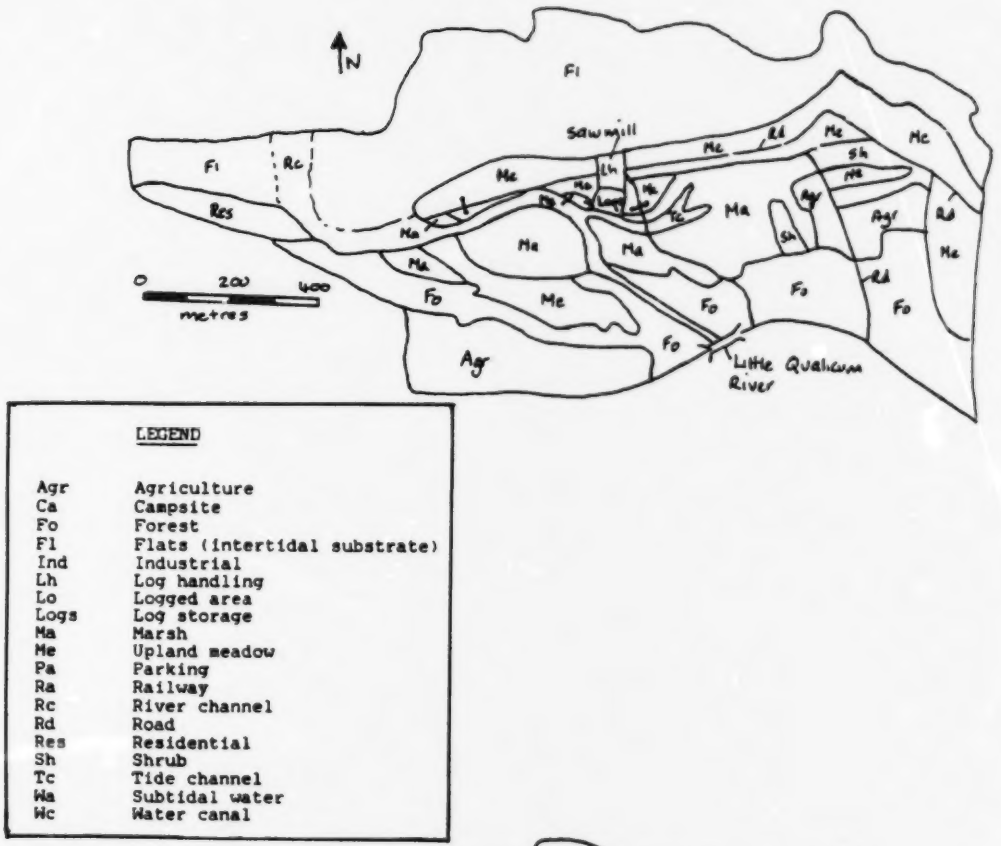


Figure 17. Map of French Creek in 1984.

Figure 18. Map of the Little Qualicum River estuary in 1949.



LEGEND

Agr	Agriculture
Ca	Campsite
Fo	Forest
Fl	Flats (intertidal substrate)
Ind	Industrial
Lh	Log handling
Lo	Logged area
Logs	Log storage
Ma	Marsh
Me	Upland meadow
Pa	Parking
Ra	Railway
Rc	River channel
Rd	Road
Res	Residential
Sh	Shrub
Tc	Tide channel
Wa	Subtidal water
Wc	Water canal

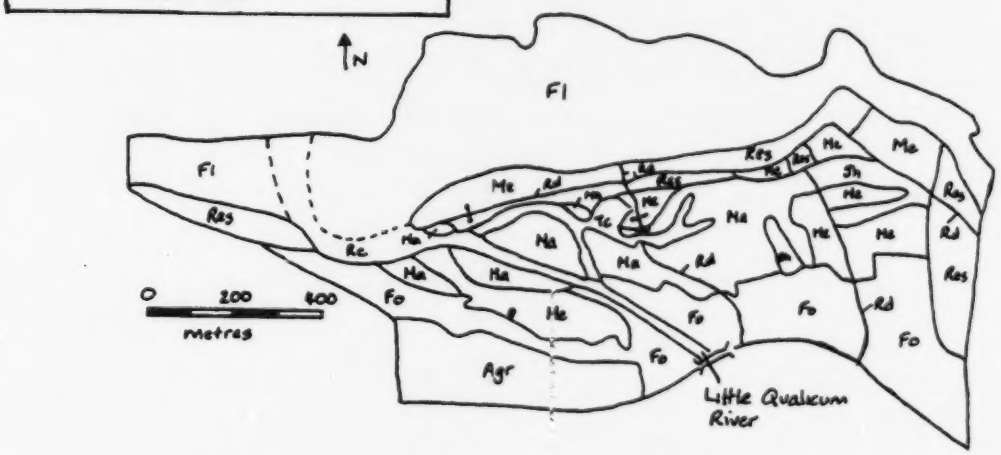
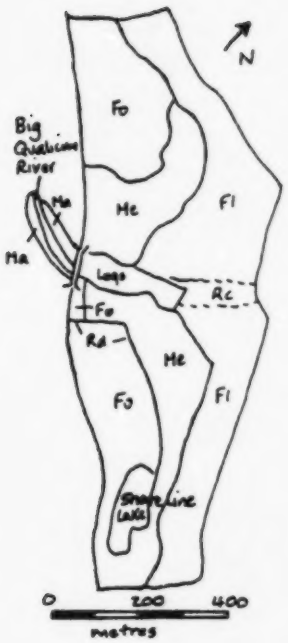


Figure 19. Map of the Little Qualicum River estuary in 1984.

Figure 20. Map of the Big Qualicum River estuary in 1951.



	LEGEND
Agr	Agriculture
Ca	Campsite
Fo	Forest
Fl	Flats (intertidal substrate)
Ind	Industrial
Lh	Log handling
Lo	Logged area
Logs	Log storage
Ma	Marsh
Me	Upland meadow
Pa	Parking
Ra	Railway
Rc	River channel
Rd	Road
Res	Residential
Sh	Shrub
Tc	Tide channel
Wa	Subtidal water
Wc	Water canal

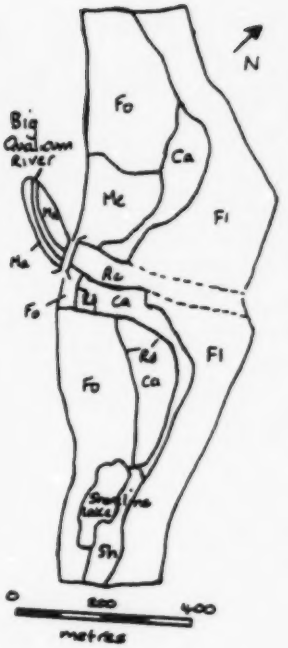
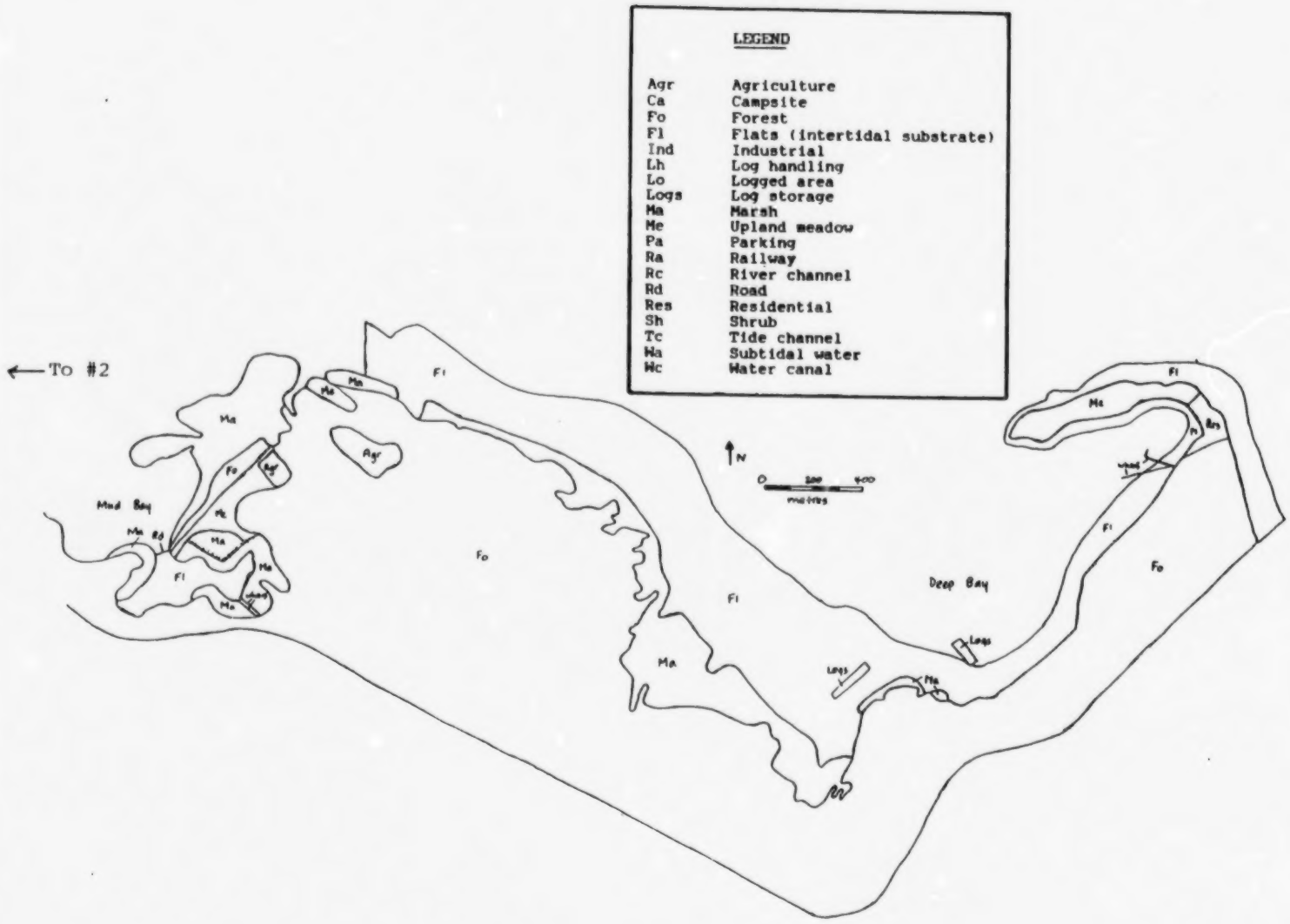


Figure 21. Map of the Big Qualicum River estuary in 1984.

Figure 22. Map of Baynes Sound #1 in 1951.



To #3

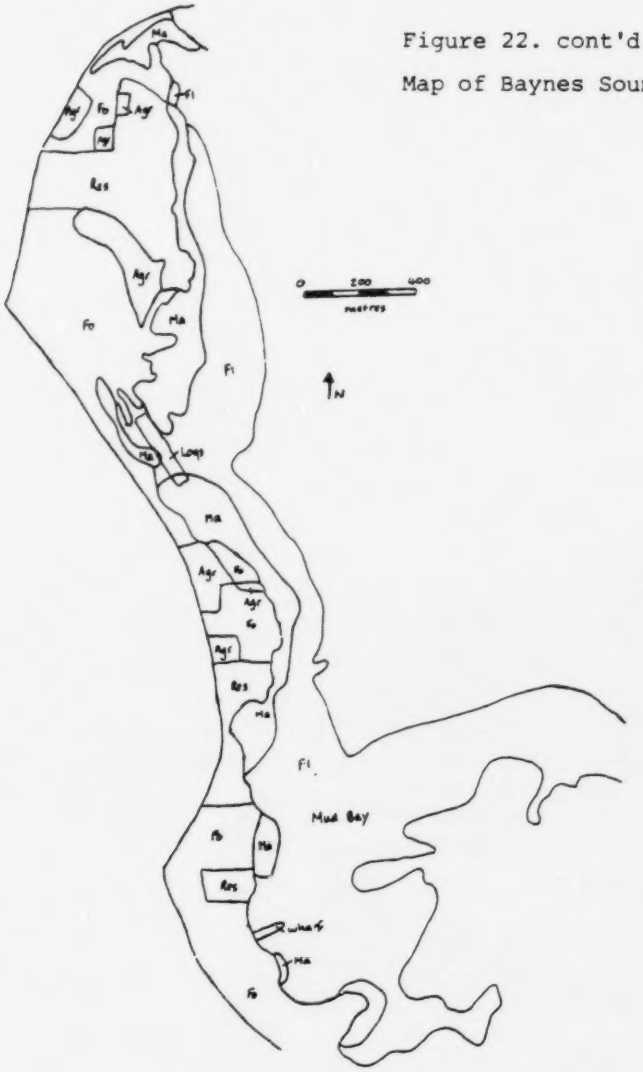


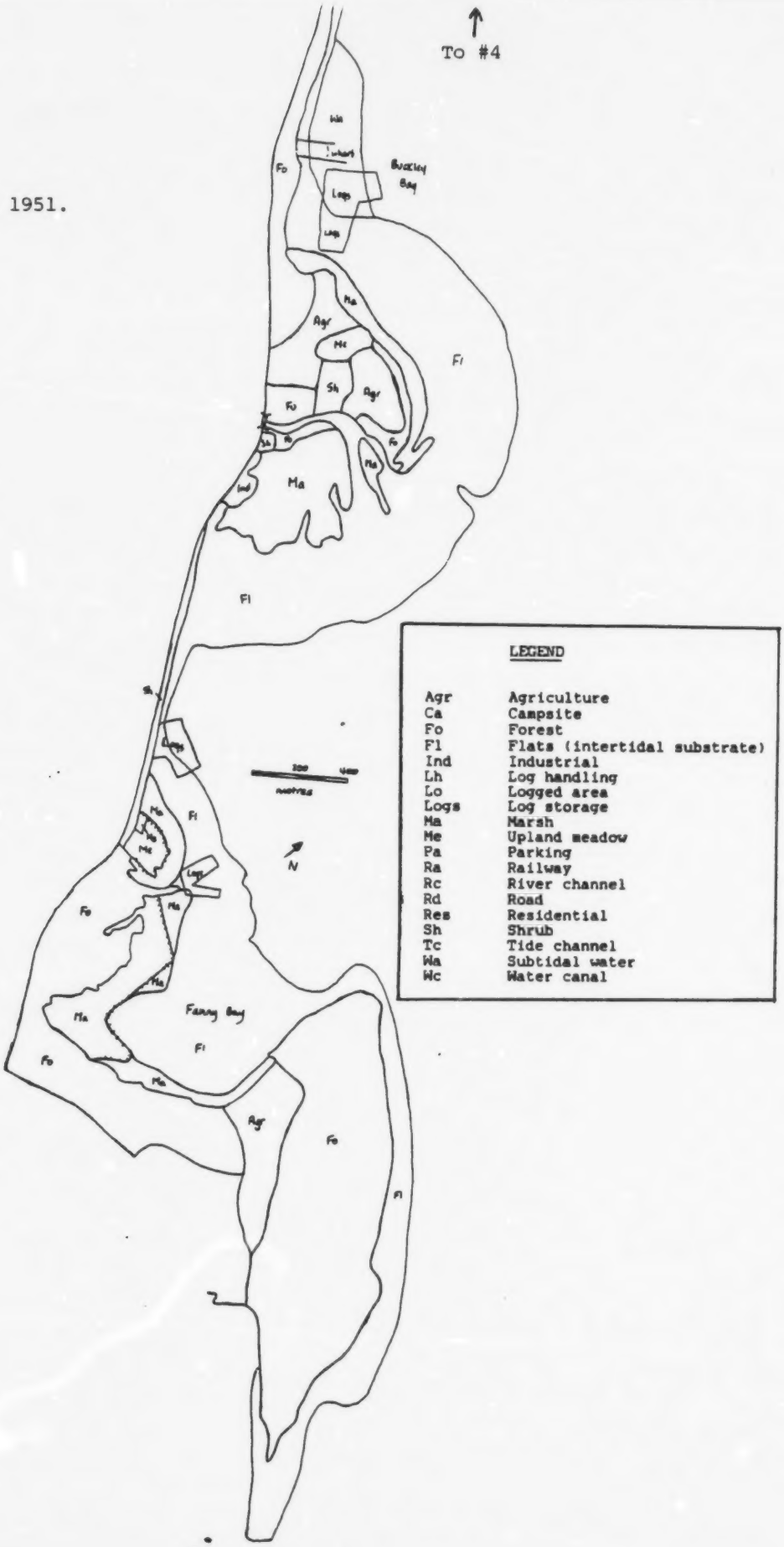
Figure 22. cont'd

Map of Baynes Sound #2 in 1951.

	LEGEND
Agr	Agriculture
Ca	Campsite
Fo	Forest
Fl	Flats (intertidal substrate)
Ind	Industrial
Lh	Log handling
Lo	Logged area
Logs	Log storage
Ma	Marsh
Me	Upland meadow
Pa	Parking
Ra	Railway
Rc	River channel
Rd	Road
Res	Residential
Sh	Shrub
Tc	Tide channel
Wa	Subtidal water
Wc	Water canal

Figure 22. cont'd

Map of Baynes Sound #3 in 1951.



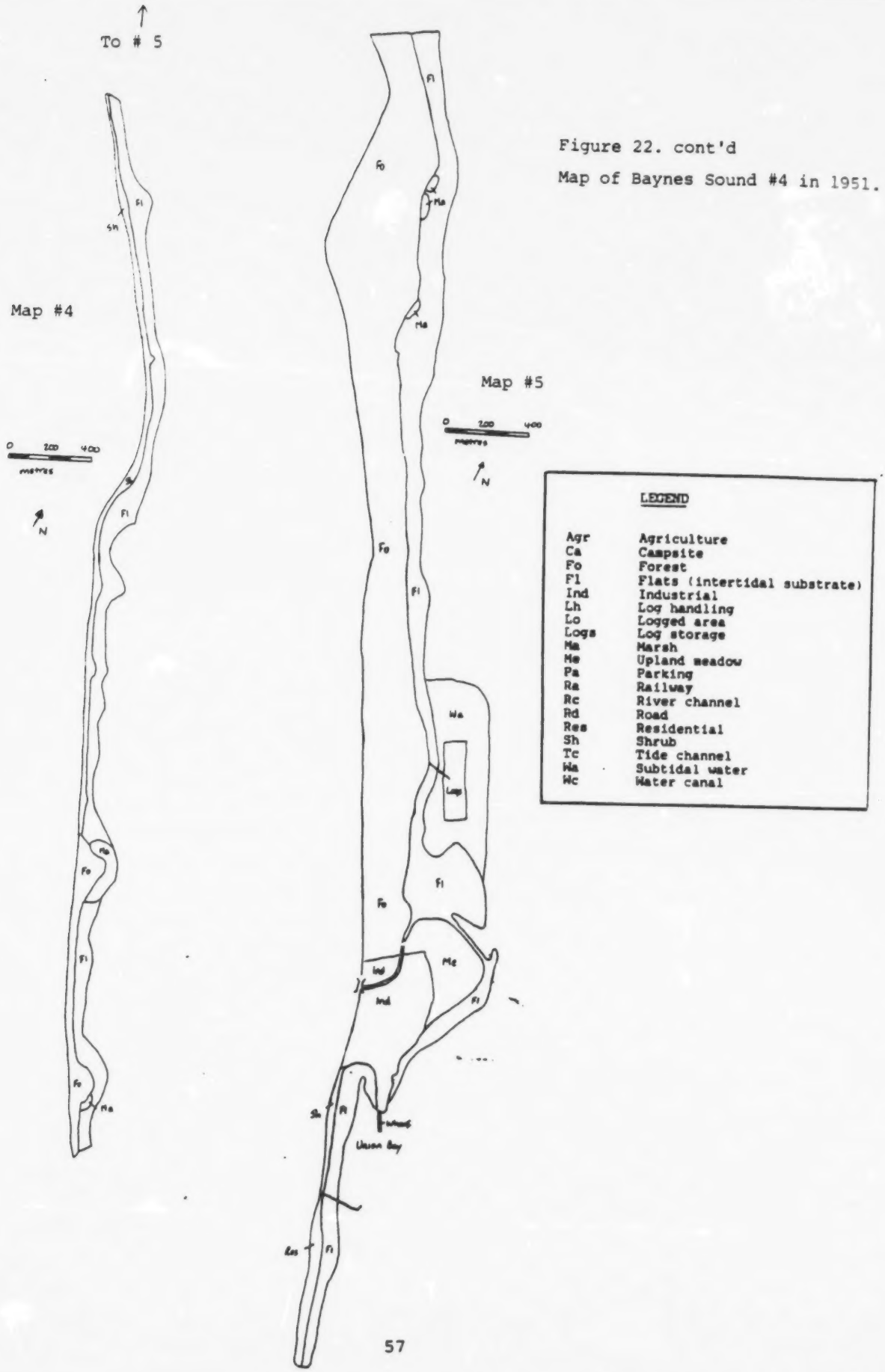


Figure 22. cont'd

Map of Baynes Sound #4 in 1951.

Figure 23. Map of Baynes Sound #1 in 1984.

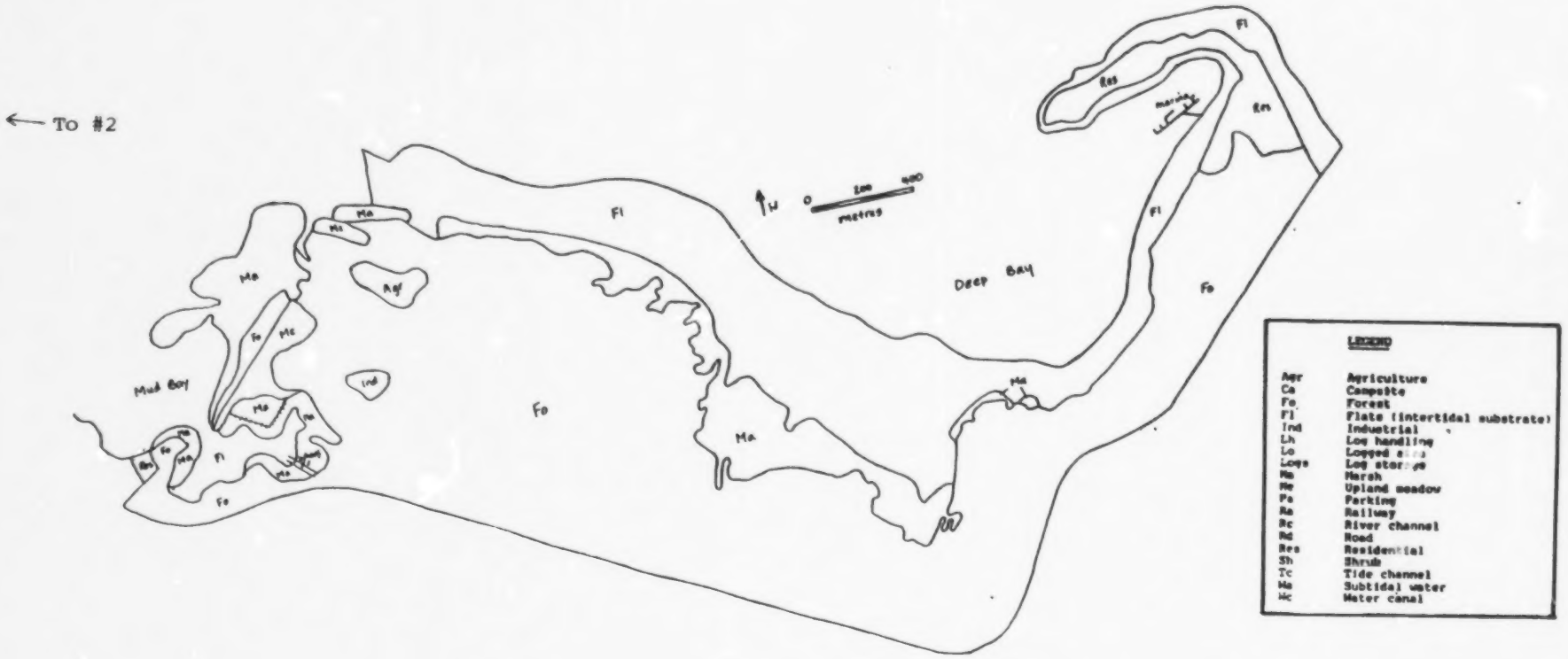


Figure 23 cont'd. Map of Baynes Sound #2 in 1984.

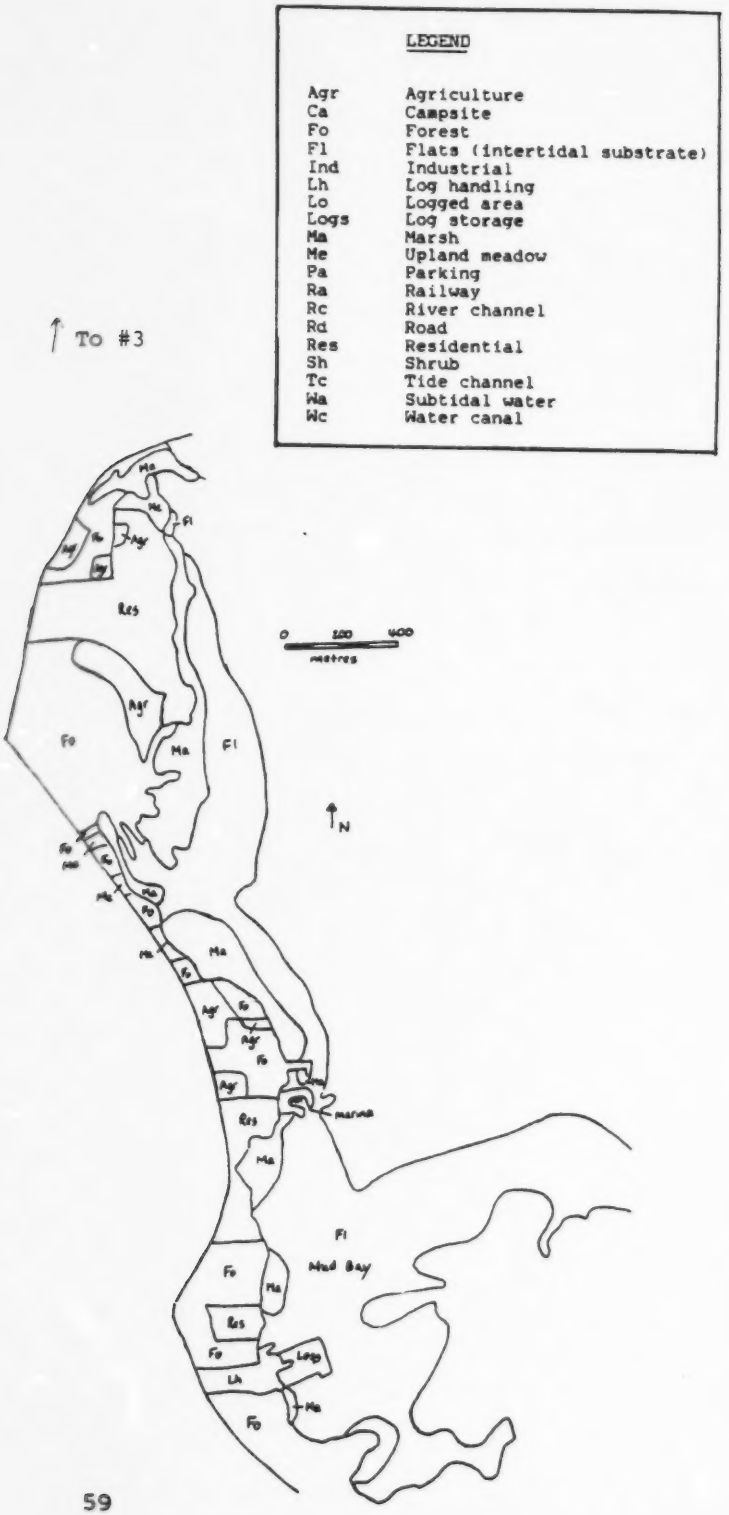
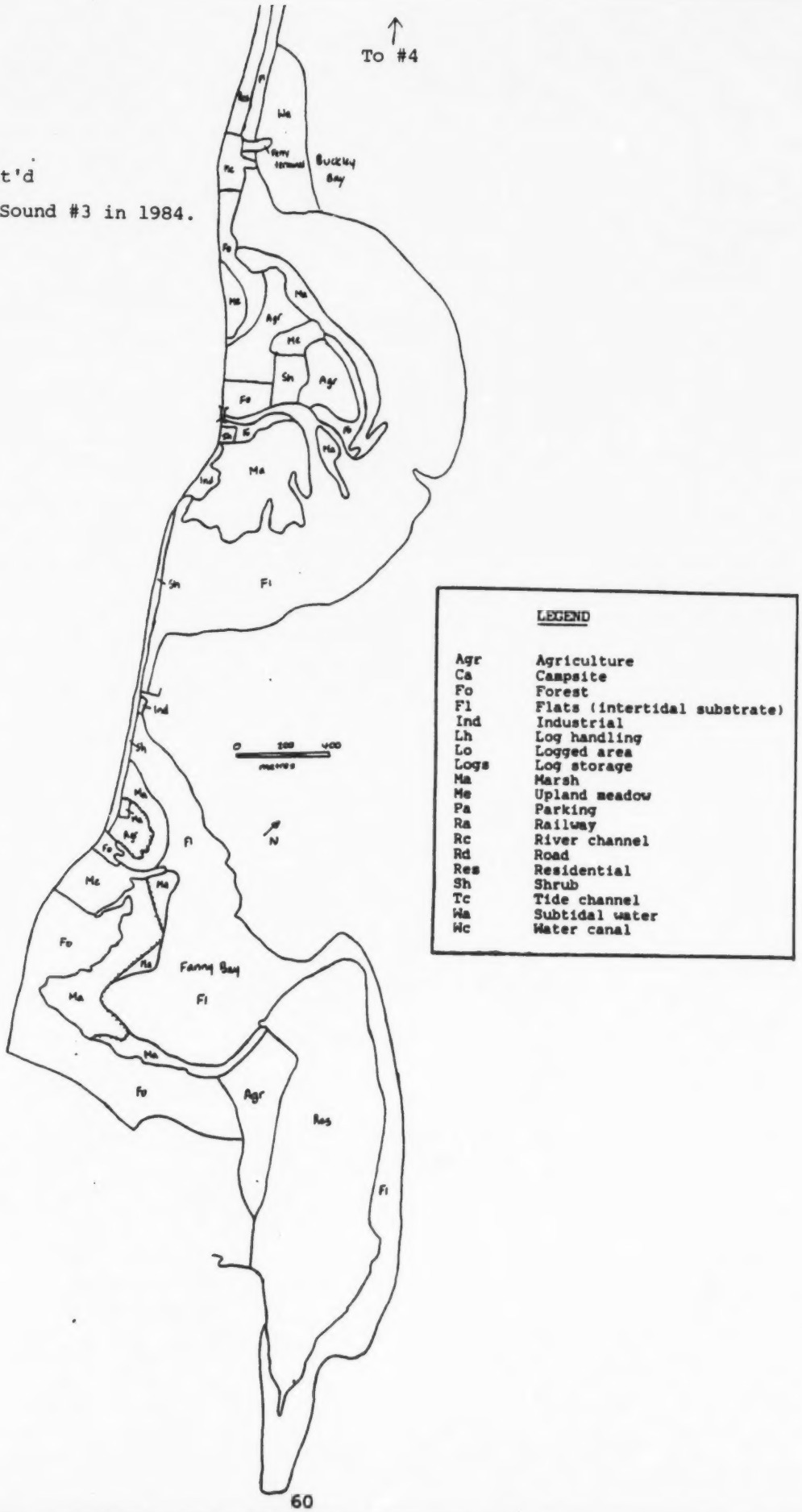


Figure 23. cont'd

Map of Baynes Sound #3 in 1984.



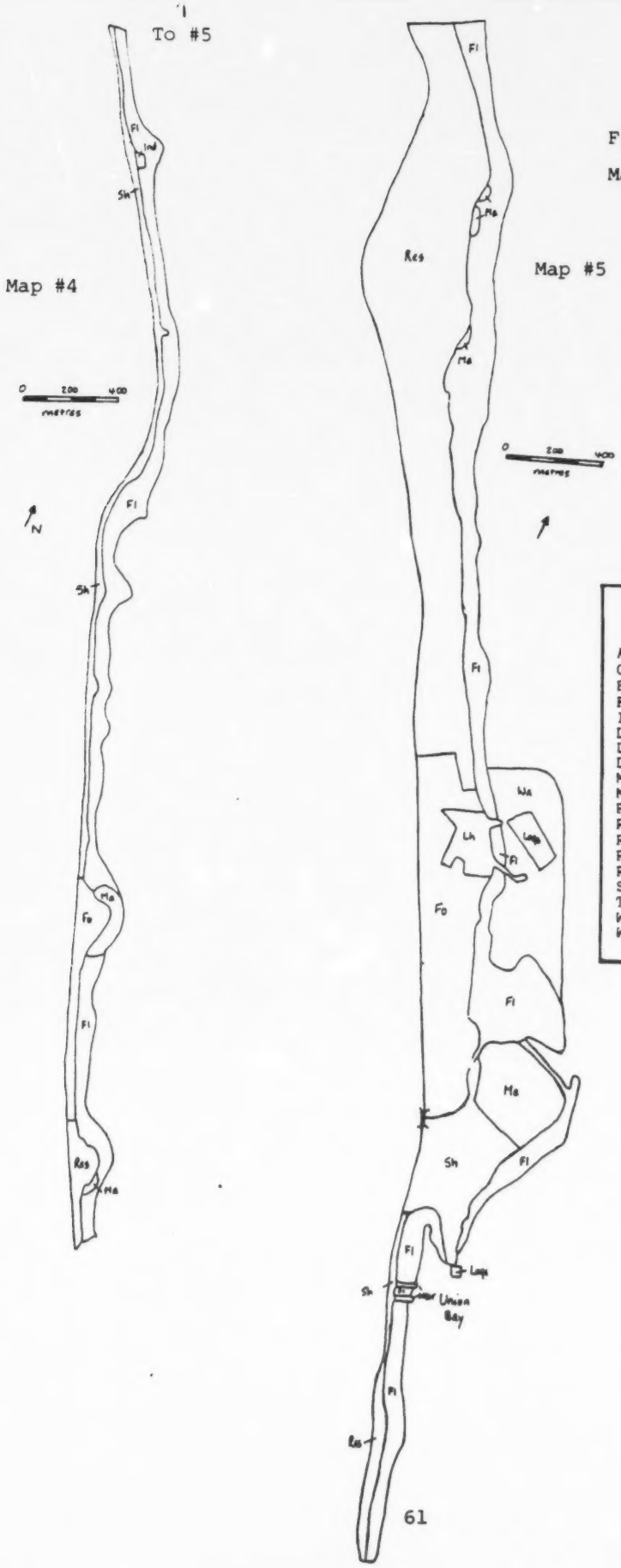


Figure 23. cont'd

Map of Baynes Sound #4 in 1984.

LEGEND	
Agr	Agriculture
Ca	Campsite
Fo	Forest
Fl	Flats (intertidal substrate)
Ind	Industrial
Lh	Log handling
Lo	Logged area
Logs	Log storage
Ma	Marsh
Me	Upland meadow
Pa	Parking
Ra	Railway
Rc	River channel
Rd	Road
Res	Residential
Sh	Shrub
Tc	Tide channel
Wa	Subtidal water
Wc	Water canal

Figure 24. Map of Courtenay-Comox area 1950. West half.

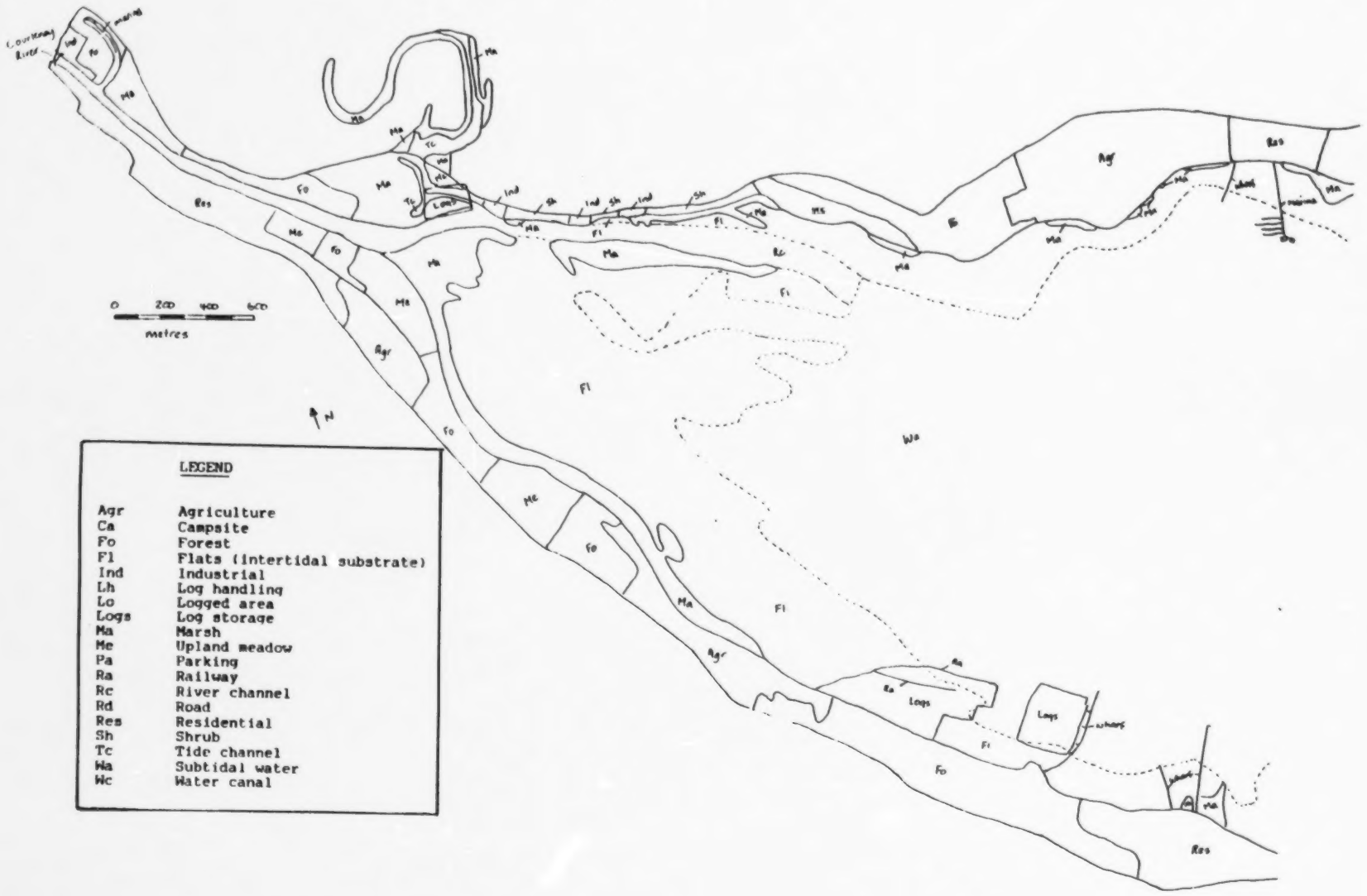
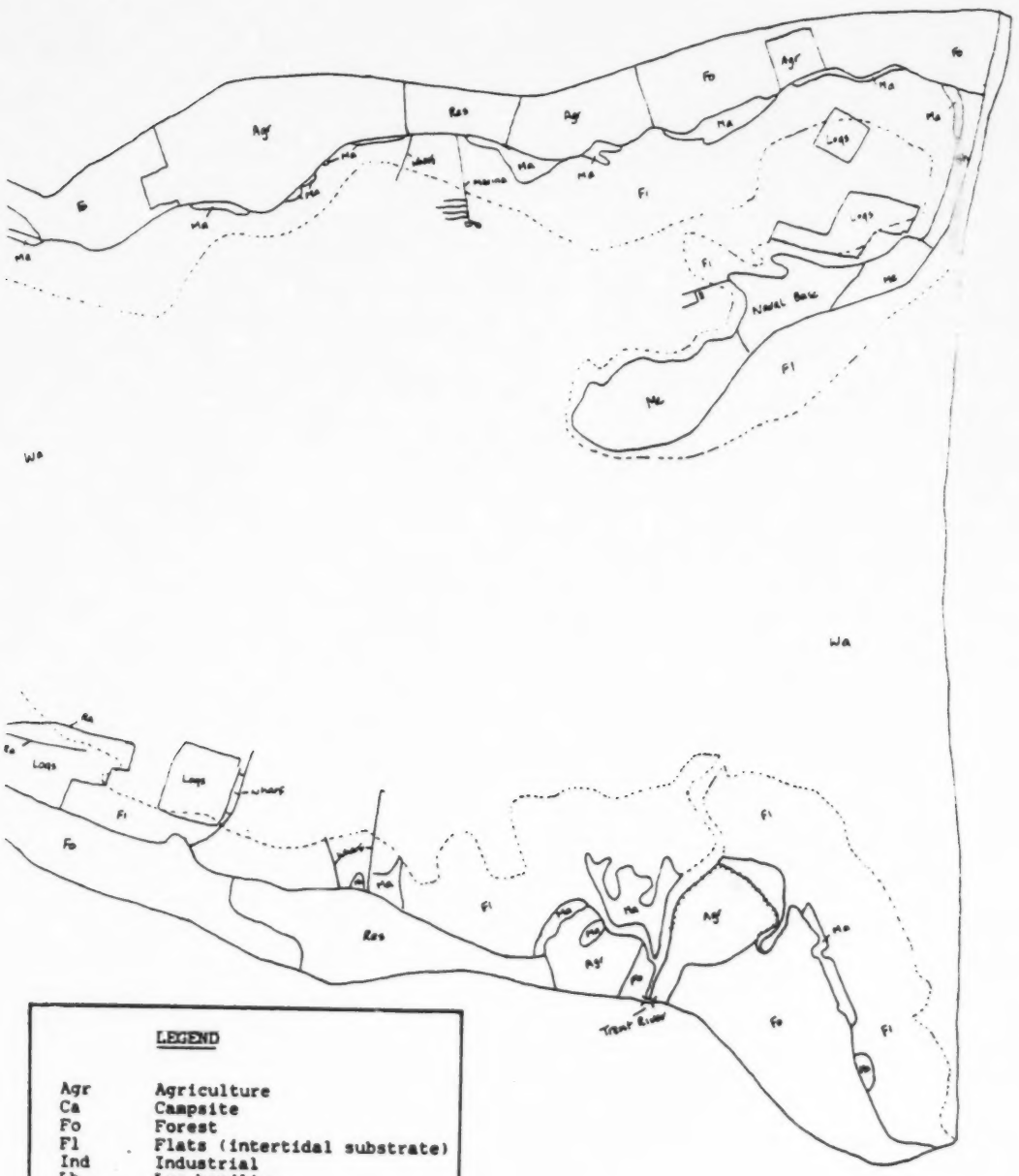


Figure 24 cont'd. Map of Courtenay-Comox area in 1950. East half.



LEGEND

Agr	Agriculture
Ca	Campsite
Fo	Forest
Fl	Flats (intertidal substrate)
Ind	Industrial
Lh	Log handling
Lo	Logged area
Logs	Log storage
Ma	Marsh
Me	Upland meadow
Pa	Parking
Ra	Railway
Rc	River channel
Rd	Road
Res	Residential
Sh	Shrub
Tc	Tide channel
Wa	Subtidal water
Wc	Water canal

Figure 25. Map of Courtenay-Comox area in 1986. West half.

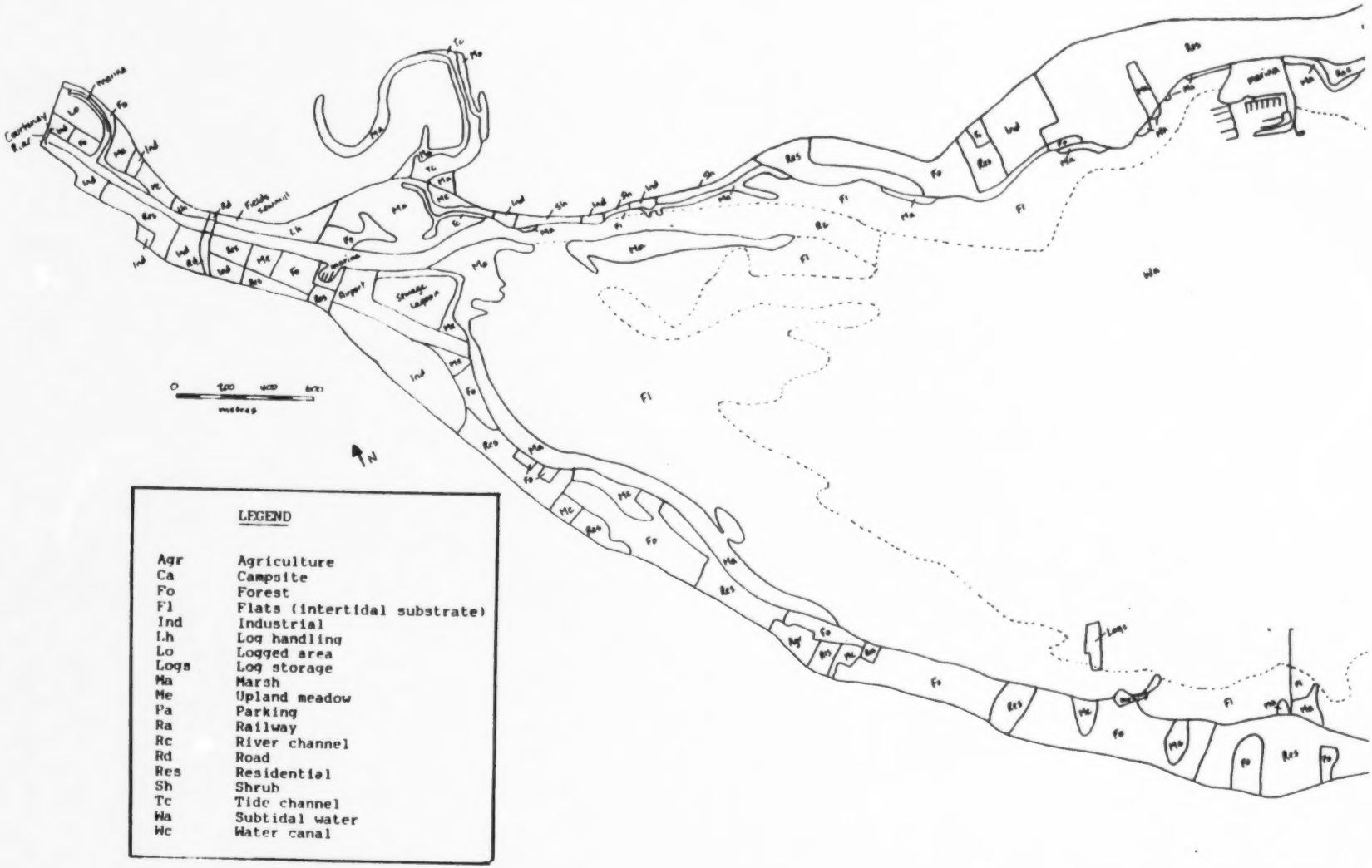
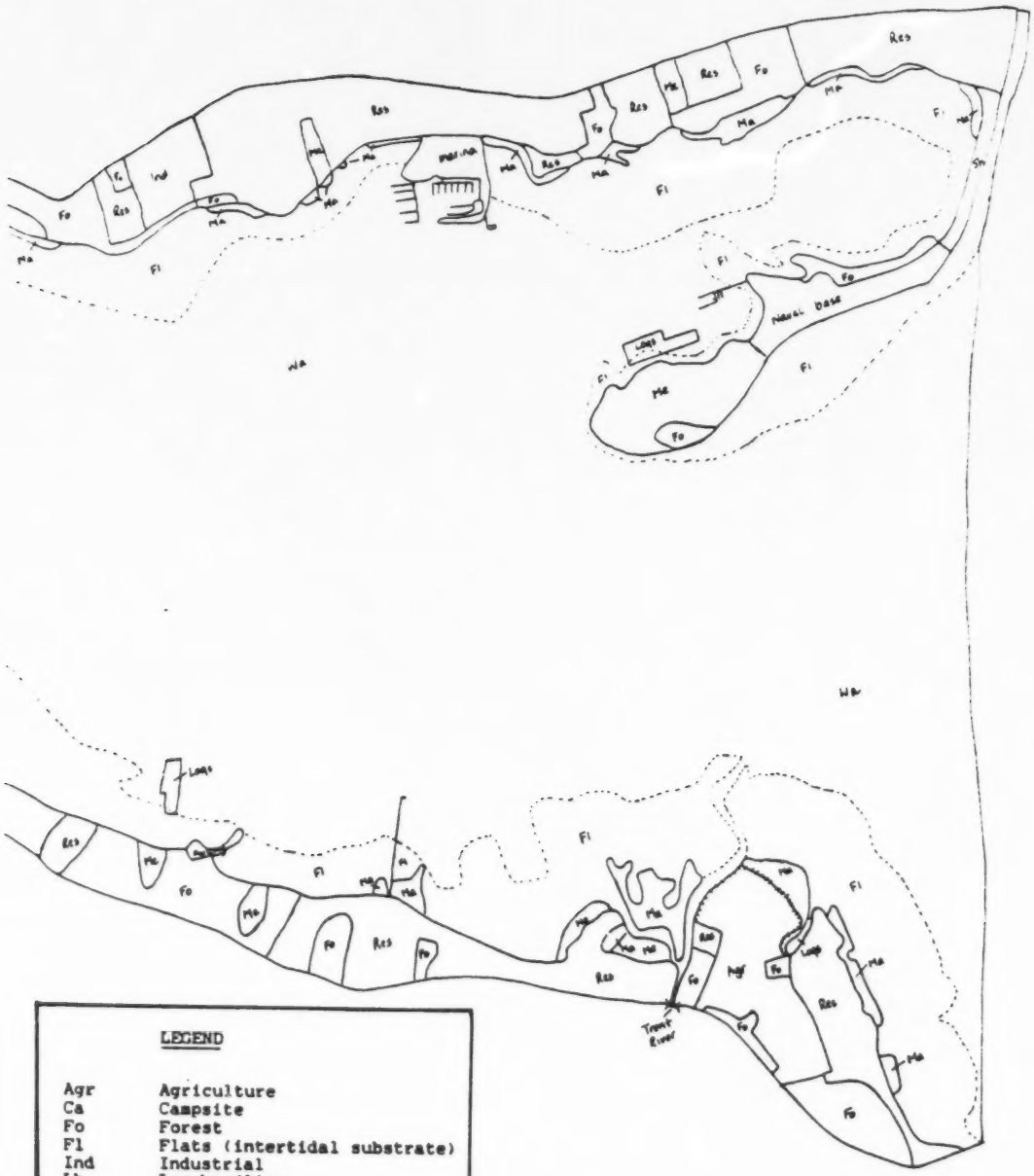


Figure 25 cont'd. Map of Courtenay-Comox area in 1986. East half.



LEGEND

Agr	Agriculture
Ca	Campsite
Fo	Forest
Fl	Flats (intertidal substrate)
Ind	Industrial
Lh	Log handling
Lo	Logged area
Logs	Log storage
Ma	Marsh
Me	Upland meadow
Pa	Parking
Ra	Railway
Rc	River channel
Rd	Road
Res	Residential
Sh	Shrub
Tc	Tide channel
Wa	Subtidal water
Wc	Water canal

Figure 26. Map of Oyster River and Black Creek in 1938.

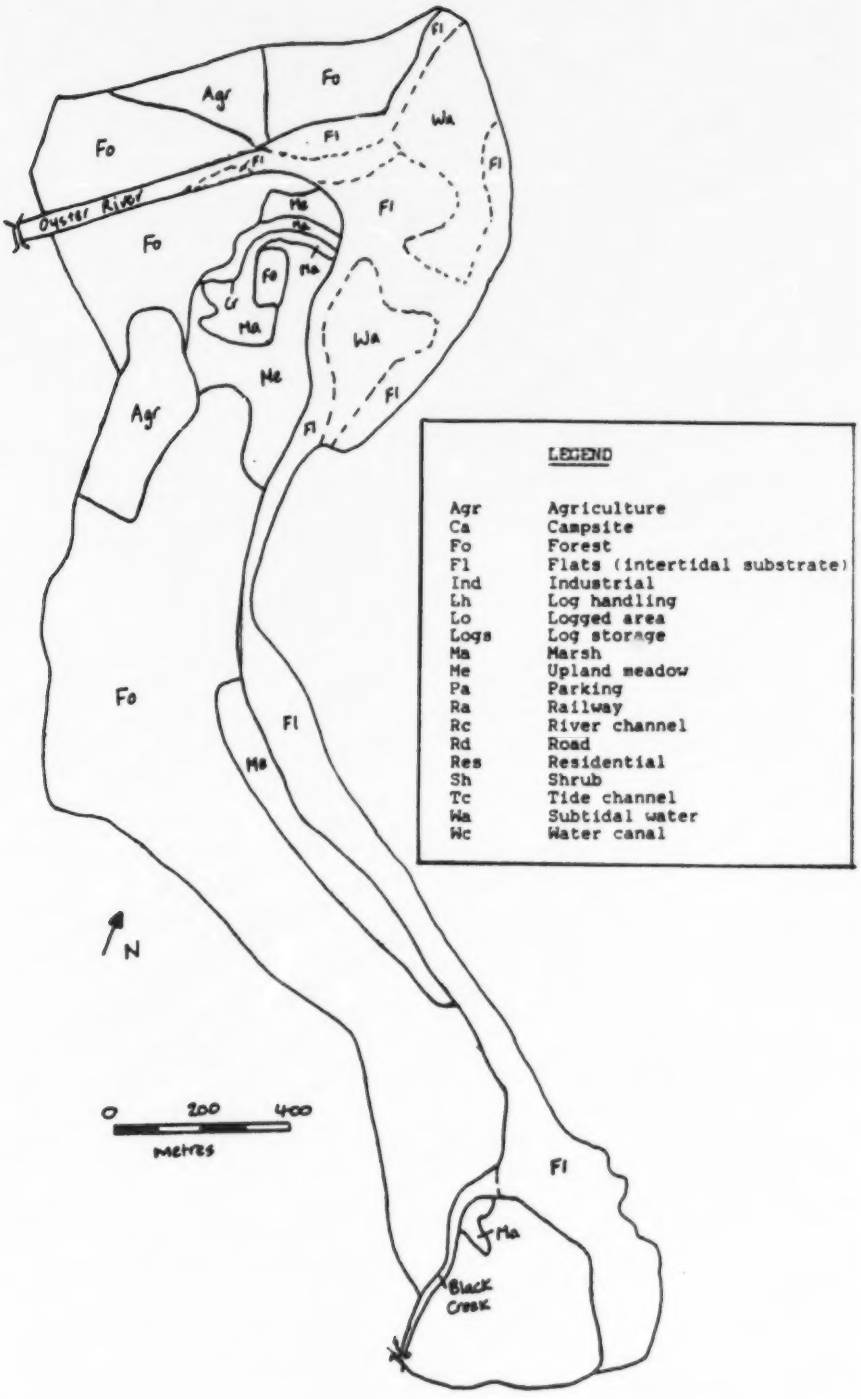


Figure 27. Map of Oyster River and Black Creek in 1984.

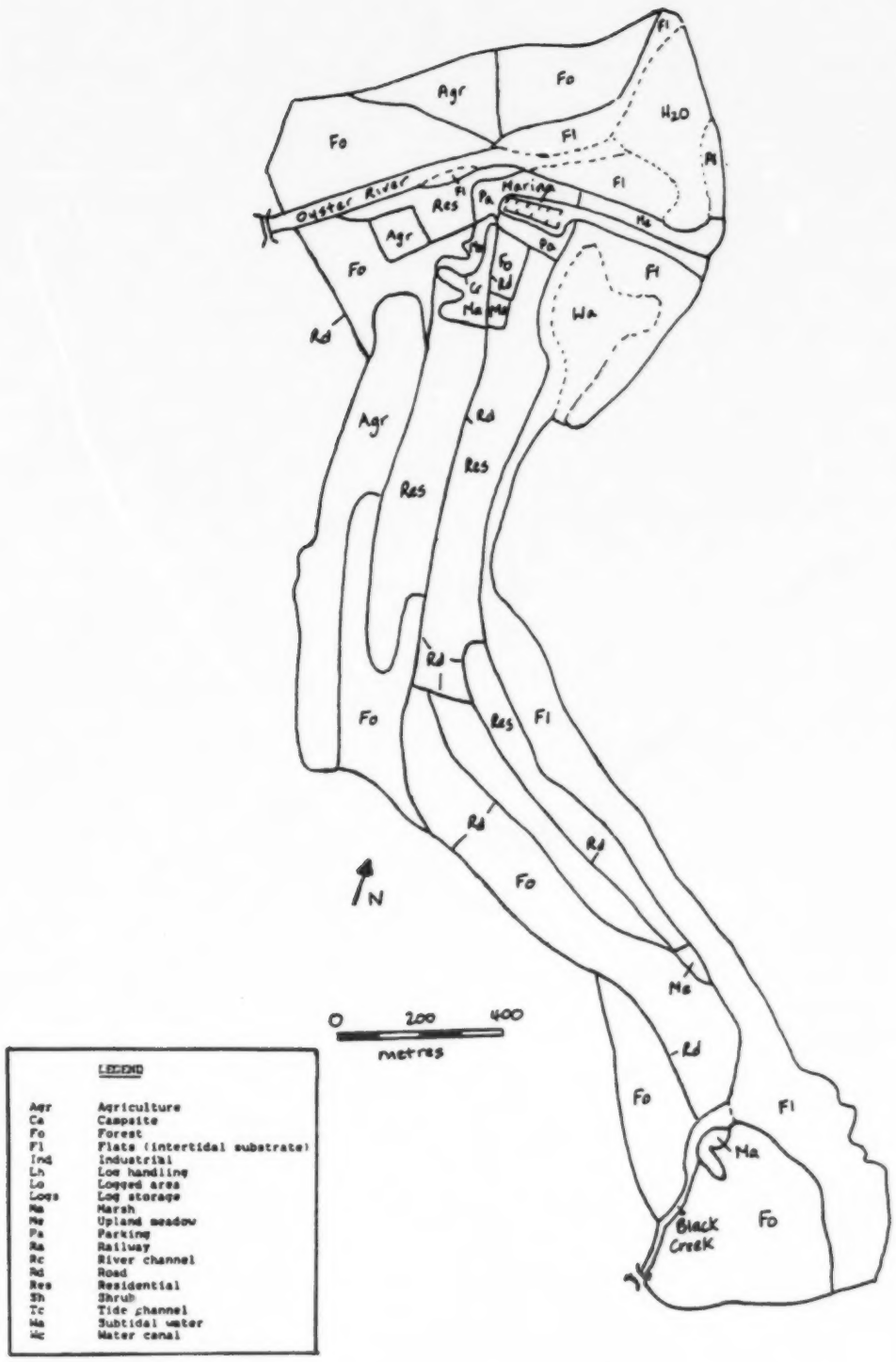
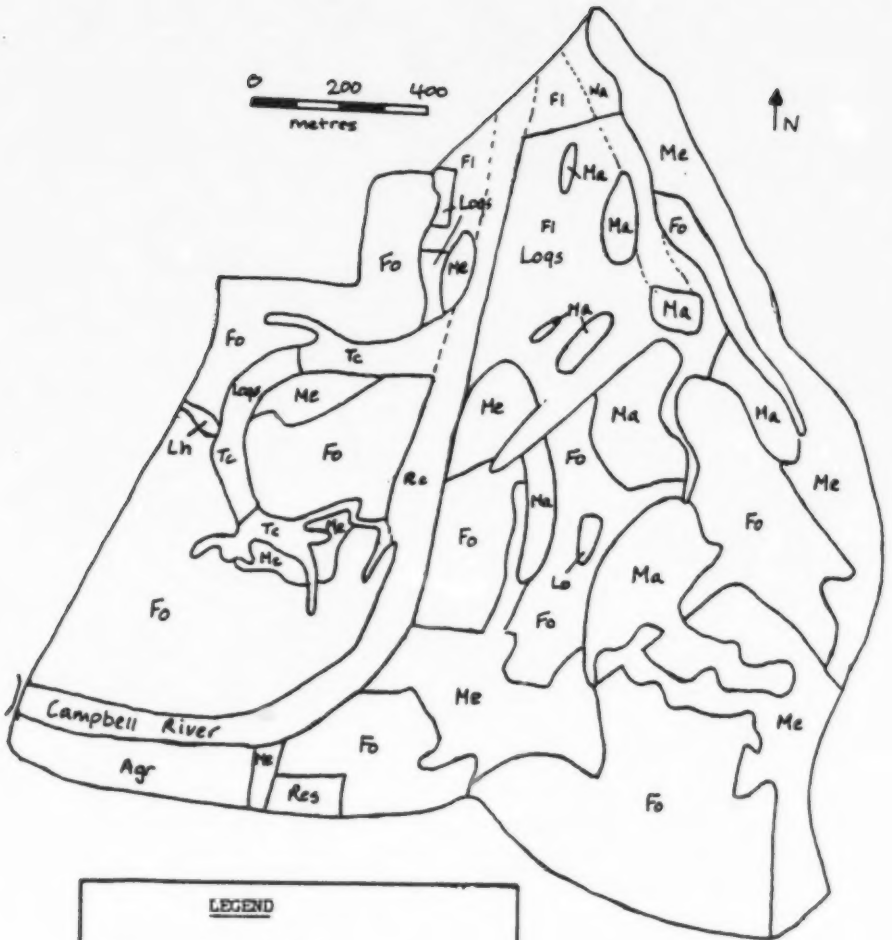


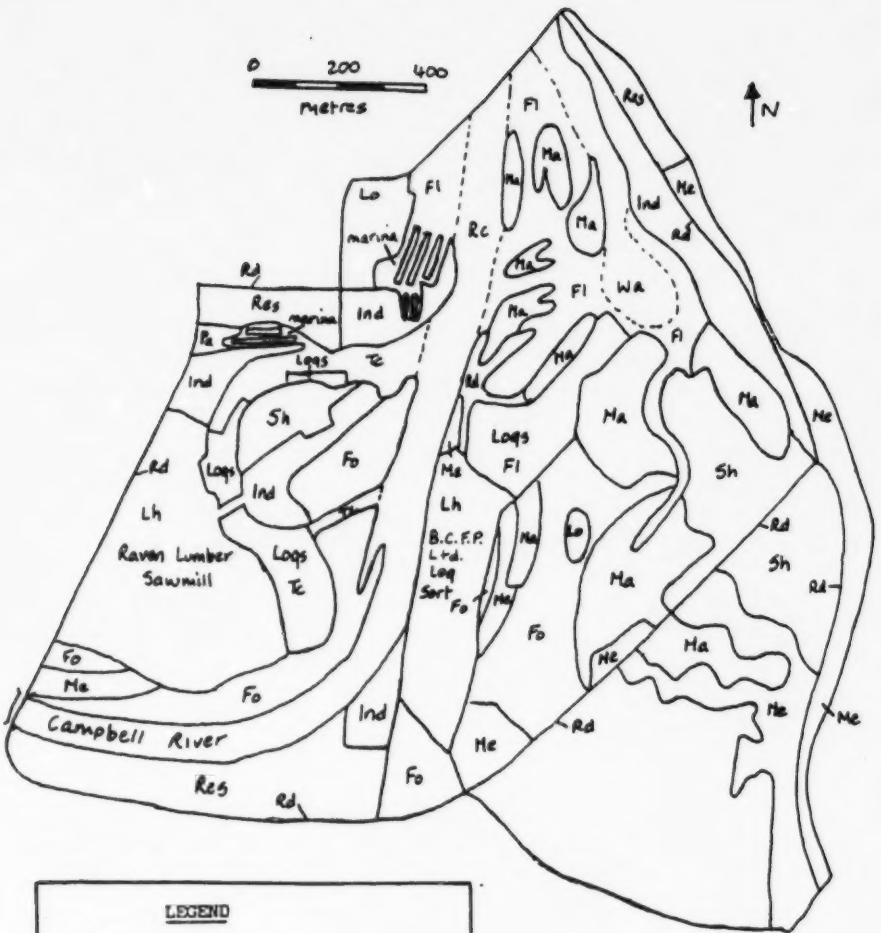
Figure 28. Map of Campbell River estuary in 1938.



LEGEND

Agr	Agriculture
Ca	Campsite
Fo	Forest
Fl	Flats (intertidal substrate)
Ind	Industrial
Lh	Log handling
Lo	Logged area
Logs	Log storage
Ma	Marsh
Me	Upland meadow
Pa	Parking
Ra	Railway
Rc	River channel
Rd	Road
Res	Residential
Sh	Shrub
Tc	Tide channel
Wa	Subtidal water
Wc	Water canal

Figure 29. Map of Campbell River estuary in 1986.



LEGEND

Agr	Agriculture
Ca	Campsite
Fo	Forest
Fl	Flats (intertidal substrate)
Ind	Industrial
Lh	Log handling
Lo	Logged area
Logs	Log storage
Ma	Marsh
Me	Upland meadow
Pa	Parking
Ra	Railway
Rc	River channel
Rd	Road
Res	Residential
Sh	Shrub
Tc	Tide channel
Wa	Subtidal water
Wc	Water canal

Appendix 1. Rating of study sites according to the British Columbia Ministry of Environment and Parks (Hunter et al. 1985)[1]

	Water-fowl	Wild-life	Fish	Produc-tivity	Total resource value	Social Factor	Imminence of deve-lopment	Enhance. Rehab. Potential	Total Rating
Campbell River estuary	3	0	3	2	8	3	3	3	17
Oyster River estuary	1	0	3	1	5	3	2	1	11
Black Creek Estuary	1	0	3	1	5	3	3	2	13
Comox-Courtenay area	3	1	3	3	10	3	3	3	19
Baynes Sound area	3	1	3	3	10	3	3	3	19
Big Qualicum River estuary	3	0	3	1	7	3	1	1	12
Little Qualicum River estuary	3	1	3	3	10	3	2	2	17
French Creek estuary	1	0	2	1	4	3	1	1	9
Englishman River estuary	3	1	3	2	9	3	3	2	17
Northwest Bay area	1	0	3	2	6	3	1	1	11
Nanoose/Bonell Creek estuary	3	1	3	3	10	3	2	3	18
Nanaimo River estuary	3	1	3	3	10	3	2	3	18
Ladysmith Harbour	3	0	3	2	8	3	2	2	15
Chemainus River estuary	3	1	3	3	10	3	3	3	19
Cowichan River estuary	3	1	3	3	10	3	3	3	19

[1] DEFINITION OF RATING FACTORS

RESOURCE VALUE RATINGS

A. Waterfowl

Waterfowl (ducks, geese and swans) numbers were used as an indicator of waterbird use of an area. Criteria for rating each area are listed below.

Ratings	Criteria
1	less than 200 waterfowl recorded on each survey of area
2	200 or more waterfowl recorded on at least one survey of area
3	200 or more waterfowl recorded on three or more surveys of area

B. Other wildlife

This rating factor pertains to use of the site by high profile wildlife species. Species considered were: trumpeter swans (>70); peregrine falcons; sandhill cranes; grizzly bears; Roosevelt elk; harbour seals; and killer whales.

Ratings	Criteria
0	area does not receive significant use by any of the species listed above
1	area receives significant use by one or more of the species above

C. Fish

An estimation of the importance of the area to fish was based primarily on salmon escapement records. The overriding assumption was that wetlands were important to the well-being of fish. Although salmon were the major species considered, herring spawn sites and shellfish areas were also considered important and rated appropriately.

Ratings	Criteria
1	salmon escapement historically <1500
2	salmon escapement historically 1500-7500
3	salmon escapement historically >7500

Numbers include the total of all species of salmon.

D. Productivity

Productivity generally referred to the relative amount or proportion of marsh and fine textured intertidal flats present on a site. General knowledge of the individuals involved and the WB Coastal Photo Catalogue were used to derive these ratings.

Ratings	Criteria
1	sites having minimal areas of marsh and fine textured intertidal flats usually resulting from steep gradient streams and/or unprotected locations.
2	sites intermediate to 1 and 3
3	sites having proportionately high areas of marsh and flats usually associated with low gradient streams and protected locations.

E. Social Value Rating

This rating reflects the proximity of the wetland to human population centres and/or the public appreciation of the wetland.

Rating	Criteria
1	remote sites for which the general public is perceived to have no special appreciation
2	intermediate to 1 and 3
3	sites located near a relatively large centre of population and/or which the general public perceives as having high natural resource value.

F. Imminence of Development

This rating reflects the current development pressures on the wetland. It is an estimation of the probability of development or future development of the area based on knowledge of BCMOE regional staff.

Ratings	Criteria
1	no existing or anticipated development pressure
2	probability of development and/or significance of development considered moderate
3	high probability of development with potentially negative impacts on the fish and wildlife resources

G. Rehabilitation and Enhancement Value

This rating indicates the current potential of a site for rehabilitation/enhancement for fish and waterfowl. In keeping with BCMOE policy non-impacted sites are not considered to have rehabilitation/enhancement potential. This rating is based on the known state of the art of management techniques and does not consider cost/benefit.

Ratings	Criteria
1	no rehabilitation or enhancement potential (pristine, relatively undisturbed or irreversibly degraded)
2	moderate rehabilitation or enhancement potential
3	productive areas with development of disturbance amenable to current rehabilitation/ enhancement techniques

Appendix 2. Aerial photographs used for the study.

	"Prior to 1951"	1957 or 1958	1962, 1964 or 1965	1975	1984 or 1986
Cowichan River	BC 247:100 1946 1:31680	BC 2086:63-64 1957 1:31680	BC 5047:64-65 69-70 1962 1:31680	BC 7760:124-126, 240-241 1975 1:15840	BC 84029:48-49 1984 1:20000
Chemainus River	BC 1053:18-20 1950 1:31680	BC 2086:33-35 1957 1:31680	BC 5047:117-120 1962 1:31680	BC 7751:201-204, 264-269 1975 1:15840	BC 84029:142-146 1984 1:20000
Ladysmith Harbour	BC 1053:23 1950 1:31680	BC 2086:29 1957 1:31680	BC 5047:113 1962 1:31680	BC 7751:189-190 1975 1:15870	BC 86007:56-67 1986 1:16000
Nanaimo Harbour	A 4503:89-91 A 4504:10-13 1932 1:15000	BC 2086:8-10 1957 1:31680	BC 5047:149-151 1962 1:31680	BC 7754:87-91, 192-195 1975 1:15840	BC 86007:110-113, 133-135 1986 1:16000
Nanoose/Bonell Creeks	BC 814:90 1949 1:31680	BC 2086:85 1957 1:31680	BC 5047:91-92 1962 1:31680	BC 7751:149-150 1975 1:15840	BC 84029:104-105 1984 1:20000
Northwest Bay	BC 814:91 1949 1:31680	BC 2086:86 1957 1:31680	BC 5047:100 1962 1:31680	BC 7751:160-161 1975 1:15840	BC 84012:55-56, 114 1984 1:16000
Englishman River	BC 814:94 1949 1:31680	BC 2086:88 1957 1:31680	BC 5047:94-96 1962 1:31680	BC 7760:174-176 1975 1:15840	BC 84029:4-5 1984 1:20000
French Creek	BC 814:95 1949 1:31680	BC 2086:89-90 1957 1:31680	BC 5047:96-97 1962 1:31680	BC 7760:177-178 1975 1:15840	BC 84029:2-3 1984 1:20000
Little Qualicum River	BC 816:24 1949 1:31680	BC 2086:93 1957 1:31680	BC 5047:31-32 1962 1:31680	BC 7761:280-281 1975 1:15840	BC 84027:215-216 1984 1:20000
Big Qualicum River	BC 1421:37 1951 1:31680	BC 2087:70 1957 1:31680	BC 5097:40,41 1964 1:31680	BC 7764:174-175 1975 1:15840	BC 84027:72-73 1984 1:20000
Baynes Sound	BC 1421:24-27, 33, 62-70 1951 1:31680	BC 2312:20-26 1957 1:31680	BC 5097:25-28, 43-50 1964 1:31680	BC 7766:201-213 BC 7764:266-271 1975 1:15840	BC 84024:150-159 86-89 1984 1:20000

Appendix 2. continued

	"Prior to 1951"	1957 or 1958	1962, 1964 or 1965	1975	1984 or 1986
Courtenay/Comox area	BC 1268:16-18 1950 1:31680	BC 2312:19, 28 1957 1:31680	BC 5097:51-53 1964 1:31680	BC 7764:197-200, 262-266 1975 1:15840	BC 86024:117-121, 161-165 1986 1:16000
Oyster River and Black Creek	BC 80:58 1938 1:31680	BC 2312:11 1957 1:31680	BC 5097:75-76 1964 1:31680	BC 7761:243-244 1975 1:15840	BC 84024:134-135 1984 1:20000
Campbell River	BC 79:91-93 1938 1:31680	BC 2249:22-23, 35 1958 1:15840	BC4321:134-135 1965 1:15840	BC 5667:58-59 1975 1:31680	BC 86002:63-64 1986 1:18000

Appendix 3. Planimetric base maps and references for marsh habitat.

	NTS map sheet number and planimetric maps	Vegetation maps used to determine the location of marshes
Cowichan River	92B 12g,h 92B 13a,b	Coastal Resources Folio; B.C. Ministry of Environment habitat map; Bell and Kallman (1976a); Kennedy (1982); Cowichan Estuary Task Force (1980).
Chemainus River	92B 13g	Coastal Resources Folio; B.C. Ministry of Environment habitat map; Bell and Kallman (1976a); Kennedy (1982).
Ladysmith Harbour	92G 4c	
Nanaimo River	92G 4e,f	Coastal Resources Folio; Bell and Kallman (1976b); Kennedy (1982).
Nanoose/Bonell Creeks	92F 8b	Dawe and White (1986); Kennedy (1982).
Northwest Bay	92F 8b	
Englishman River	92F 8c	Kennedy (1982)
French Creek	92F 8c	
Little Qualicum	92F 7a 92F 8d	Dawe and White (1982); Kennedy (1982).
Big Qualicum River	92F 7h	Kennedy (1982).
Baynes Sound	92F 7f,g 92F 10c,d	Baynes Sound Crown Foreshore Plan (B.C. Ministry of Environment).
Courtenay/ Comox area	92F 10e	B.C. Ministry of Environment Estuarine habitat map; Morris et al. (1979); Kennedy (1982); Coastal Resources Folio.
Oyster River and Black Creek	92G 14a	Morris et al. (1979); Kennedy (1982)
Campbell River	92K 3b,c	Raymond et al. (1985); Coastal Resources Folio; Bell and Thompson (1977); Kennedy (1982).